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THE EXPORT OF NUTRIENTS FROM SURFACE COAL MINES

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ABSTRACT

Elevated levels of the nutrients nitrogen and phosphorus in the aquatic environment can cause excessive growth of algae and toxicity to aquatic organisms. There are many potential sources of nutrients but releases from nitrogen-based explosives used in the surface mining of coal have only recently been investigated. A study conducted by Pommen (1983) at the Fording coal mine in southeastern British Columbia in 1979-80 found that up to 6% of the nitrogen content of the explosives used at the mine was released to the receiving environment. However, subsequent studies of water quality near coal mines suggested the Pommen formula may overestimate nitrogen release and exaggerate potential receiving water impacts.

The purpose of this EP study was to verify the Pommen findings and to investigate phosphorus releases from coal mines. Historical nitrogen and phosphorus data were reviewed from 1980 to 1985 for the five surface coal mines in southeastern British Columbia. Specific data were collected from April 1985 to March 1986 for two of these mines.

In general, the quantity of explosives-derived nitrogen released to the receiving environment increased with the amount of slurry explosives used under wet blasting conditions as found by Pommen. Mines using only ammonium nitrate/fuel oil (ANFO) explosive in dry conditions were found to release 0.2% of the nitrogen compared to 1% predicted by the Pommen formula. The quantity of nitrogen released by mines using significant (>20%) quantities of slurry explosives was predicted to be 0.94% ANFO +5.1% slurry, close to the 1% ANFO +6% slurry as suggested by Pommen

Methods which can be used to speciate the inorganic nitrogen load according to ammonia, nitrite, and nitrate forms and to apportion loadings according to season are also presented.

Although elevated phosphorus concentrations were found in small drainages at the two mines studied in detail, effluent levels were not significant when compared to background levels in the receiving waters. Conclusions regarding phosphorus are considered speculative given the limited data base.

RESUME

La présence de niveaux élevés des éléments nutritifs, azote et phosphore, dans le milieu aquatique peut causer la croissance excesive k'algues et la toxiciteé des organixmes aquatiques. Il y a plusieurs sources potentielles de ces nutritifs, mais seuls les rejets provenant des explosifs à base d'azote, utilisés dans les mines à ciel ouvert, ont été recemment examinés. L'étude entreprise par Pommen (1983) à la mine de charbon Fording au sud-est de la Colombie Britannique en 1979-80 a conclu que 6% de l'azote contenu dans les explosifs, utilisés à la mine, a été libéré dans le milieu environnant. D,autres études de la qualité de l'eau adjacente à des mines de charbon suggèrent que la formule adoptée par Pommen surestime les quantités d'azote libérées et exagère l'impacte possible sur les cours d'eau adjacents.

L'objectif de cette étude entreprise par la Protection de l'environnement est de vérifier les résultats de Pommen et d'examiner les rejets phosphoreux provenant des mines de charbon. Les rejets d'azote et de phosphore, provenant de 5 mines de charbon à ciel ouvert du sud-est de la Colombie Britannique, ont été examinés pour les années 1980 à 1985. On a aussi examiné les données de deux de ces mines entre avril 85 et mars 86.

Généralement, la quantité d'azote (les explosifs rejeté dans le milieu environnant augmente avec la quantité d'explosifs en suspension utilisée dans des conditions humides, ceci correspond aux conclusions de Pommen. La quantité d'azote rejetée des mines, qui utilisent un mélange de nitrate d'ammonium/fuel oil (NAFO) comme explosifs sous des sous des conditions non-humides, équivaut à 0.2% de l'azote comparé à 1% prédit par la formule de Pommen. Aussi, les quantités d'azote rejetées par les mines utilisant d'importantes proportions (20%) d'explosifs en suspension ont été prédites être égales à 0.94% du NAFO + 5.1% de la suspension, ceci se compare bien aux résultats suggérés par Pommen de 1% du NAFO + 6% de la suspension.

Ce document présente aussi des méthodes qui peuvent être utilisées pour identifier les concentrations d'azotre inorganique basées sur les quantités d'ammoniac, de nitrite et de nitrate présentes dans un échantillon et leur répartition selon les saisons.

Malgré que la concentration de phosphore observée, dans des petits égouts des deux mines examinées en détail, était élevée néanmoins elle n'avait pas d'importance comparée aux concentrations naturelles des cours d'eau récepteurs. Les conclusions qui ont trait au phosphore ne sont pas fondées à cause du nombre limité des données.

EXECUTIVE SUMMARY

The nutrients nitrogen and phosphorus are required by all living things, but excessive levels of these elements in receiving waters can lead to severe environmental degradation. Man's activities can result in increased loadings of inorganic and organic nitrogen and phosphorus compounds to the environment which can cause excessive growth of algae and toxicity to aquatic organisms.

Potential sources of these nutrients include precipitation, land drainage, and municipal and industrial discharges. Potential releases from mining operations have only recently been documented.

Studies conducted in 1978, 1979, and 1983 in the Kootenay coal fields of southeastern British Columbia found significant releases of nitrogen from coal mines. These releases originated from nitrogen-based explosives, either ammonium nitrate/fuel oil (ANFO) or slurry (a mixture of oxidizers, aqueous medium, guar gum thickener, and cross-linking gel), used in the mining process. A study conducted by Pommen found up to 6% of explosives-derived nitrogen used at the Fording Coal mine in 1979-80 was released to the receiving environment. Further analysis of data from the Fording mine and other mines in British Columbia by Pommen suggested that about 1% of the ANFO and 6% of the slurry nitrogen would be released from these mines. This formula has been used to predict the nitrogen released from explosives use at other proposed mines.

Subsequent cursory studies of water quality near coal mines in the Kootenay coal fields suggested that the Pommen formula may overestimate nitrogen release. Overestimating the nitrogen loss may exaggerate potential receiving water impacts and delay approvals for new mines. An extensive study was, therefore, required to obtain nitrogen species concentration and flow data from the Kootenay coal fields to determine the actual nitrogen loss and, thereby, test the Pommen formula. This study was conducted in 1985-86 by Environment Canada and the results are contained in this report.

Historical data collected by the companies and provincial Waste Management Branch were obtained for all the mines in the Kootenay coal fields; Fording Coal, Westar-Greenhills, Crows Nest Resources-Line Creek, Westar-Balmer, and Byron Creek Collieries. In addition, sampling was conducted from April 1985 to March 1986 to obtain data specifically for this study from the Crows Nest Resources-Line Creek and Westar-Balmer mines. Analyses were also performed for phosphorus species in effluents and receiving waters associated with Westar-Balmar and Crows Nest Resources-Line Creek to determine if the mines were also a source of phosphorus to the environment.

In 1985 (Fording, Westar-Greenhills, Byron Creek) and 1985-86 (Westar-Balmer, Crows Nest Resources-Line Creek), approximately 13 700 tonnes of explosives expressed as N were used in the Kootenay coal fields. Based on the Pommen formula, up to 211 tonnes of nitrogen could be released to the receiving waters. Actual water quality data, however, indicated about 238 tonnes of nitrogen were released from the mines. More nitrogen was released than predicted from the Fording and Westar-Balmer mines and less from the Westar-Greenhills, Crows Nest Resources-Line Creek, and Byron Creek mines. These calculations assumed that the quantity of nitrogen measured in a given year was released from explosive nitrogen used in that year. While this may not be strictly true, for first order estimates of nitrogen release it is probably a valid assumption.

In total, 15 sets of annual explosives nitrogen loss data were examined from 1980 to 1986 for the five mines in the Kootenay coal fields (Byron Creek - 2 sets, Westar-Greenhills - 2 sets, Fording - 5 sets, Crows Nest Resources-Line Creek - 3 sets; Westar-Balmar - 3 sets) to test the Pommen formula. The percentage nitrogen loss ranged from 0.1% for the Westar-Greenhills operation in 1985 to 4.3% for the Westar-Balmer operation in 1984. Generally, three mines exhibited nitrogen losses less than 0.3% (Byron Creek Collieries, Westar-Greenhills, and Crows Nest Resources-Line Creek) and two exhibited losses greater than 1% (Fording Coal and Westar-Balmer). The former mines used less than 1% slurry in dry blasting conditions, while the latter used from 18% to 70% slurry in wetter blasting conditions.

Mines that used little slurry ($\leq$1% of total explosive as N) released a mean of 0.2% of the ANFO (expressed as nitrogen), while mines that used significant quantities of slurry ($\geq$20% of total explosive as N) released 0.94% of the ANFO and 5.1% of the slurry (r = 0.87). A transitional formula of 0.1% of the ANFO and 8.5% of the slurry may be appropriate for mines that use between 1% and 20% slurry explosive. These relationships are recommended to predict nitrogen release from coal mines in other areas. The new relationship developed for mines with significant slurry use is only about 15% lower than the Pommen formula, while the mean value for low slurry use mines was 80% lower. As such, the Pommen formula provided a reasonable prediction of nitrogen release from mines with high slurry use but significantly overpredicted release from mines with low slurry use. Findings confirmed Pommen's conclusion that the proportion of slurry explosive used (determined by wet or dry blasting conditions) is the key factor in predicting nitrogen release from coal mines.

Most of the nitrogen in effluents was present in the nitrate form (average 87%) with lesser amounts as ammonia (11%) and nitrite (2%). At the receiving water sites upstream of the mines, about 47% of the inorganic nitrogen was present as nitrate and 43% and 9% was present as ammonia and nitrite, respectively. Downstream of the mines, 87% of the inorganic nitrogen was present as nitrate, 10% was present as ammonia, and 3% was present as nitrite. The increase in the proportion of nitrate downstream of the mines compared to upstream reflects the large nitrate loadings from mine effluents. Since explosives contain large amounts of both nitrate and ammonia, the relatively high proportion of nitrate in effluents indicates significant conversion of ammonia to nitrate (nitrification) occurs between the source of nitrogen (pits and waste dumping) and the effluent discharge to receiving waters. Predictions for other mines should assume that the majority of inorganic nitrogen released will be present as nitrate.

Loadings of nitrogen generally followed flow patterns as suggested by Pommen. Larger loadings were noted during the freshet (April to June) compared to other times of the year.

The analysis of phosphorus data was more difficult than that for nitrogen as impacts on receiving water quality were not as apparent and the phosphorus levels were near detection limits. However, total dissolved phosphorus (TDP) and soluble reactive phosphorus (SRP) concentrations in the two receiving water streams examined, Michel Creek near Westar-Balmer and Line Creek near Crows Nest Resources-Line Creek, showed little change downstream of the mine as compared to upstream. Therefore, these two mines did not appear to be major sources of phosphorus to the receiving waters.

Elevated phosphorus levels were found in drainages and pools on the mine properties but these did not affect the total dissolved phosphorus and soluble reactive phosphorus levels in the major effluent discharges. Five of six major effluent streams from the two mines contained total dissolved phosphorus, on average, at concentrations lower than upstream receiving water levels. For other mines, average total dissolved phosphorus concentrations in effluents may be assumed to equal upstream receiving water levels and, in the worst case scenario, to be 0.002 mg/L above background levels. Similar findings and conclusions were reached for soluble reactive phosphorus.

The mines did appear to be a source of total phosphorus. The average total phosphorus concentration for the six effluent streams studied was 0.044 mg/L greater than upstream receiving water levels. Based on this result, other mines should also be considered as potential sources of total phosphorus.

Because of the limited data base, conclusions regarding phosphorus release at other coal mines are considered to be speculative. Data from natural drainages, groundwater, and discharges from areas disturbed by exploration may provide better estimates of phosphorus release from proposed coal mines.

Further studies are recommended to determine the actual loss of explosives nitrogen from mines using between 1% and 20% slurry explosive, to quantify the nitrogen released from coal mines in climatic zones other than that encountered in the Kootenay coal fields (such as the coastal region of British Columbia), and to improve the data base on phosphorus levels in effluents and receiving waters from coal mines.

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1 INTRODUCTION

Nutrients are environmental substances (elements or compounds) necessary for the growth and development of plants and animals. Nitrogen, phosphorus, and sulphur are found in varying proportions to carbon depending on the chemical nature of the compounds in which they occur. A pattern for the circulation of these elements was established in nature when micro-organisms, plants, and animals appeared on earth. The pattern was set by the physical and chemical environment, the chemical nature of these elements, and by the geographic distribution of the plants and animals. However, man's activities have great effect on these patterns and cycles.

In particular, the nitrogen and phosphorus cycles in the aquatic environment have been altered by increased loading of inorganic and organic nitrogen and phosphorus compounds. This may result in excessive growth of algae and toxicity to other aquatic organisms causing deterioration of the aquatic environment. The extent of this deterioration is dependent on the concentration and loading of these nutrient releases and the sensitivity of the receiving environment.

There are several potential point and non-point sources of nutrients to the environment. Non-point sources include precipitation, drainage from agricultural, pastural and reclaimed lands, urban land drainage, decaying vegetation, and wildlife wastes. Point sources consist of municipal and industrial effluents. Of these, the potential impacts from agricultural drainage, municipal discharges, and some industrial effluents are well known. However, the potential for nutrient release from mining has only recently been investigated. Knowledge of the nutrient releases from mines originates from a series of studies conducted in the Kootenay coal fields of southeastern British Columbia (Figure 1). Levels of nutrients in effluents from the coal mines and their impacts on the Elk River Basin have been documented (B.C. Ministry of Environment, 1976, 1978; MacDonald, 1985; Pommen, 1983).

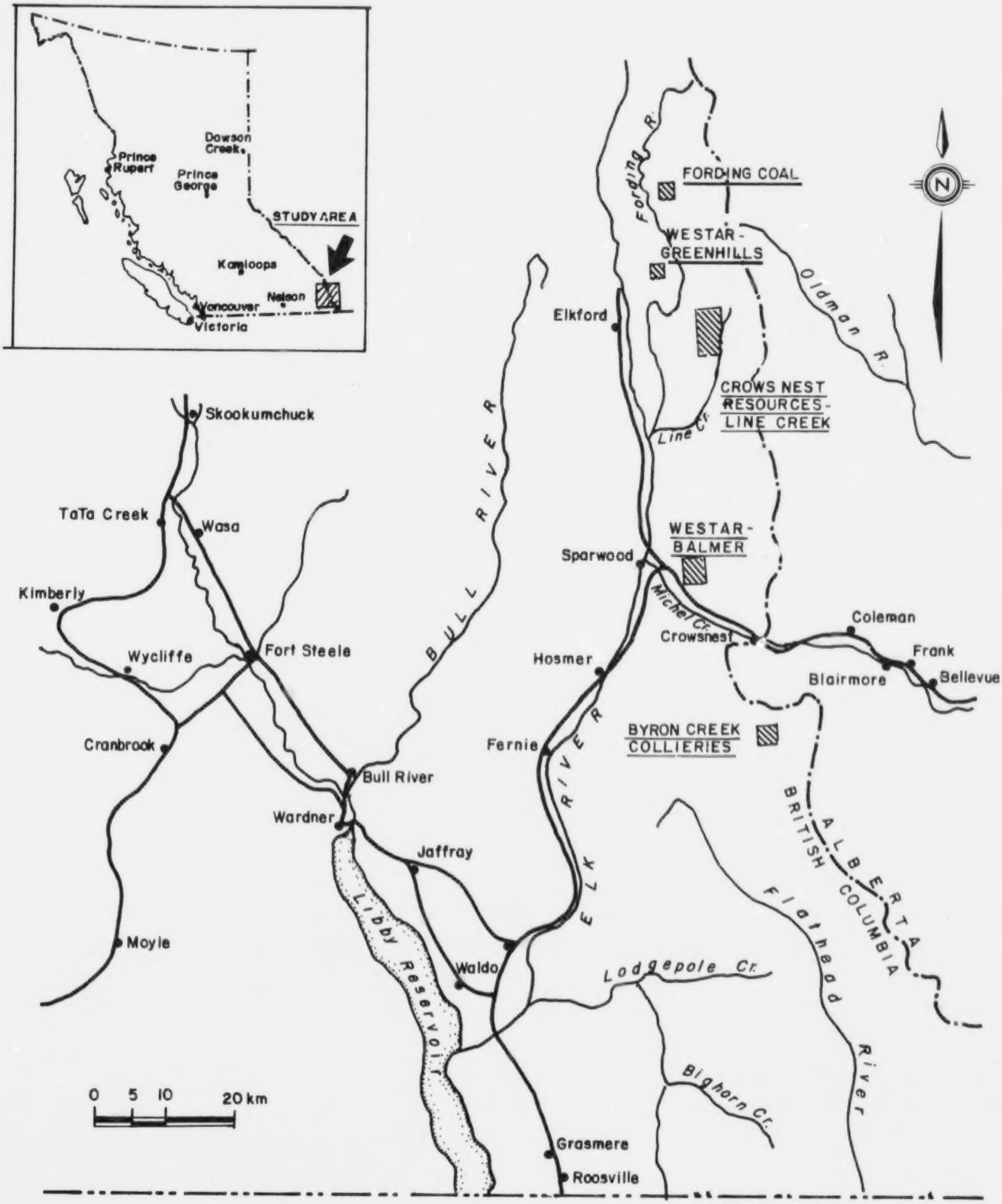

Dawson Creek
Prince Rupert
Prince George
STUDY AREA
Kamloops
Nelson
Vancouver
Victoria
Fording R.
FORDING COAL
WESTAR-GREENHILLS
Oldman R.
Elkford
CROWS NEST RESOURCES-LINE CREEK
Line Cr.
N
Skookumchuck
BULL RIVER
TaTa Creek
Wasa
WESTAR-BALMER
Sparwood
Michel Cr.
Kimberly
Crowsnest
Coleman
Frank
Bellevue
Blairmore
Wycliffe
Fort Steele
Hosmer
BYRON CREEK COLLIERIES
Cranbrook
Fernie
Bull River
ELK RIVER
Wardner
ALBERTA
BRITISH COLUMBIA
Jaffray
Libby Reservoir
Flathead River
Moyie
Waldo
Lodgepole Cr.
Bighorn Cr.
0 5 10 20 km
Grasmere
Roosville
U. S. A.

FIGURE I KOOTENAY COAL FIELDS

1.1 Previous Studies

The Ministry of Environment, Water Investigations Branch, has conducted two major water quality studies in the Elk River Basin. The Kootenay Air and Water Quality Study, Phase I, evaluated water quality data collected from 1972 to 1974. The study identified mining exploration and coal mining and its related operations as major contributors to water quality degradation in the Elk River Basin. The study was primarily concerned with suspended solids and turbidity. Although a large amount of water quality data was collected during the study, the samples were not necessarily taken during specific flow regimes or at sites of ongoing exploration activities. Also, no differentiation was made between the effects of natural or man-made sources of sediment. Therefore, the study results could not be used to relate effluent quality to receiving water quality and the biological effect.

The Kootenay Air and Water Quality Study, Phase II, examined water quality data from samples taken in 1973 and 1976. It confirmed the main conclusions of the Phase I study; that mine exploration and coal mining and its related operations were the cause of high suspended solids and turbidity in the aquatic environs of the Elk and Flathead River Basins. Logging was identified as another, albeit lesser, source. The study also examined nutrient contributions to the aquatic system, primarily with respect to agriculture and fertilized irrigated cropland. A few localized impacts were identified and recommendations were made for improved pollution control. It concluded that pollution from the various sources had not reached critical proportions primarily because contaminant concentrations were diluted in the Elk River. Almost incidentally, increased nitrogen levels were found in the Fording River below the Fording Mine. As a result, further monitoring was conducted by the Ministry of Environment and Fording Coal Ltd. from 1976-1978.

Data collected to that date suggested that the use in surface mining of large amounts of high-nitrogen content explosives may result in significant releases of nitrogen to the environment. These explosives included ammonium nitrate/fuel oil (ANFO) used in dry blasting conditions and various types of slurry explosives used in wet conditions. These explosives contain about 33% and 25% nitrogen, by weight, for ANFO and slurry, respectively.

In 1979, the Ministry of the Environment, in cooperation with Fording Coal, initiated an intensive one year study of explosives use and its effect on water quality at the Fording Coal mine. The objectives of the study were:

1. to determine quantitatively the relationship between explosives use at the mine and its effect on the water quality of the Fording River; and

2. to use this relationship to aid in the management of impacts on water quality at Fording Coal, and to aid in the prediction and management of impacts at proposed mines in the province.

Information was collected on explosives use, nitrogen concentrations and loadings in mine drainages and the Fording River, algal growth in the river, and the leaching of nitrogen from coal and spoil. The results of these studies were described in three reports (Pommen, 1983; Nordin, 1982; Nagpal, 1983).

The Pommen study examined the nitrogen concentrations and loadings in mine drainage and the Fording River and determined the total inorganic nitrogen export from the mine. The minimal data available from other metal and coal mines in Canada were also examined in the study to support the findings at Fording.

The key finding of Pommen's study was that the use of nitrogen-based explosives at the Fording mine site had the potential to impair water quality for drinking, aquatic life and recreation due to the toxicity of nitrate, nitrite and ammonia and their role in promoting algal growth. Generally, Pommen found that the nitrogen discharged from the mine was primarily nitrate with relatively small amounts of ammonia and nitrite, and, although ample nitrogen was available in receiving waters for algal growth, the growth was limited by low phosphorus levels.

Pommen concluded that nitrogen losses to receiving waters from explosive use at mines would vary substantially depending on such site specific factors as climate, mine hydrology, groundwater conditions in the pits, and the degree to which recycling of water is practiced. Data from Fording Coal and the Brenda Mine near Peachland, B.C. suggested that the range of nitrogen losses to either surface or groundwater would be in the order of 1% to 6%. The conditions at Fording Coal (e.g. wet pits and almost exclusive use of slurries for blasting, moisture surplus, and mine drainages discharging to receiving waters) probably caused a relatively high percentage of nitrogen loss from explosives. However, at the Brenda Mine, where climatic conditions were relatively dry and the use of ANFO explosives predominated, only about 1% of the nitrogen content of the explosives was lost to surface and groundwater.

Pommen suggested that nitrogen release from explosives use at mines could be predicted prior to mining and recommended an initial nitrogen loss factor of 1% nitrogen from ANFO and 6% from slurry. The nitrogen loss factor would then be multiplied by the annual quantities of ANFO and slurry explosives expected to be used to calculate an annual nitrogen loading to the receiving waters. The nitrogen loading would then be distributed over the year with the largest loadings occurring during spring snowmelt in the interior or during winter rains on the coast. These seasonal nitrogen loadings and receiving water flows could then be used to calculate receiving water nitrogen concentrations.

In 1981, a study was initiated by the Ministry of Environment to examine the relationship between nutrient levels and periphytic algal growth in the Elk River Basin. The study was initiated because excessive algal growths were possible in Elk River as a result of the combined effect of increased nitrogen concentrations originating from the explosives used at the coal mines and dissolved phosphorus loadings from municipal sewage discharges. An interim report (MacDonald, 1985) based on data collected from 1979 to 1982, served to identify the various nutrient regimes in the river system and to quantify, in a preliminary way, the relationship to algal growth. That study is continuing.

The studies mentioned previously identified elevated nitrogen releases from the southeast coal mines, and particularly Fording Coal, as posing a potential threat to water quality of the Fording River. The study conducted by Pommen proposed a method to predict nitrogen release from coal mines. This method has been used to predict releases from several proposed mines in British Columbia outside of the Kootenay coal fields. In a few cases, the predicted elevated nitrogen concentrations in receiving waters downstream of the mines were considered a threat to water quality.

A study conducted at the Byron Creek Collieries mine in the Kootenay coal fields indicated that the Pommen formula overestimated the release of nitrogen from that mine. If the Pommen formula overestimated releases for other mines, potential impacts on receiving environments may be exaggerated and unnecessary delays in approval and costs would accrue to proponents of new coal mines. A study was required to verify or modify the Pommen formula.

1.2 Study Objectives

In 1984, Environmental Protection (EP) of Conservation and Protection, Environment Canada proposed to conduct a study in 1985-86 to quantify the amount of nitrogen released from the various coal mines in the Kootenay coal fields. The rationale was that:

1. the information gathered would help resolve the regulatory agency delays in project approval arising from concerns about explosives-derived nitrogen impacts;

2. data gathered could be used to verify or modify the predictive model developed by Pommen; and,

3. phosphorus loading data would also be collected. Since the Elk River system is phosphorus limited (Nordin, 1982), and increases in nitrogen alone may not cause degradation of the aquatic environment, this study would aid the industry and regulatory agencies in assessing the significance of increased nitrogen loading to the aquatic environment in the region.

Refer directly to Sections 4 and 5 for the application of the study results to prediction of nutrient releases from other mines. Sections 1.3 through 3.5.4 cover study methods and results.

1.3 Study Methods

The study included both historical (1980 to 1985) water quality data gathered by the Ministry of Environment and mining companies, and 1985-86 data collected specifically for this study by Environmental Protection and the mining companies. Historical samples were collected and analyzed according to procedures approved by the Ministry of Environment.

Samples collected in 1985-86 were handled differently depending on whether they were collected by the mining companies throughout the year (extensive survey), or by Environmental Protection in one of four intensive surveys (April, May, June and September, 1985). Samples collected by the mining companies for EP were immediately frozen and submitted to the EP Laboratory in West Vancouver in batches, generally every month. Samples were thawed and then filtered as required by lab analyses. Analyses were begun as soon as samples were prepared. Samples collected by EP for the intensive surveys were filtered in the field where necessary and submitted to the West Vancouver Laboratory in coolers with ice packs within 24 hours of completion of the field survey.

Flow data were obtained by the mine, Water Survey of Canada (WSC), or Environmental Protection staff. EP staff determined flow by measuring stream velocity with a Mead Instruments Corporation, HP-302 Open Stream Velocity Probe, and cross-sectional area with a metre stick and fabric measuring tape. Velocity measurements were taken at 0.6 depth from the surface at several locations across the stream. Flow was obtained by multiplying water velocity by cross-sectional area for each section and summing all sections. The companies also provided information on their mining operations including waste rock and coal production, fertilizer and explosive use, and blasting practices.

These data were then used to assess the export of nitrogen and phosphorus from each mine. The results were compared to releases predicted by the Pommen formula. The results of this analysis are summarized in this report. Detailed results may be found in a separate appendix report.

Nitrogen released from explosives would be in the inorganic form (nitrate $-NO_3$, ammonia $-NH_3/NH4$, or nitrite $-NO_2$). However, some of this inorganic nitrogen could be quickly converted to organic forms by biological processes before the nitrogen reached the effluent and receiving water sampling sites. Consideration of only the inorganic nitrogen load may under- estimate the explosives loss. However, organic nitrogen from other sources cannot be separated from organic nitrogen originating from explosives. As a result, only inorganic nitrogen loadings were used, in both the Pommen study and in this study, to calculate the nitrogen export.

All nitrogen data presented in this report are expressed as N while phosphorus results are expressed as P. Phosphorus analyses included total phosphorus (TP), total dissolved phosphorus (TDP), and soluble reactive phosphorus (SRP). Analyses for all nutrient species used automated colourimetric methods as described in the Environment Canada, Environmental Protection, Laboratory Services Manual (1988).

Sampling for nitrogen species was conducted more frequently during freshet at all mines since that is the time of maximum flow and nitrogen release. Mean annual concentrations reported here were skewed by the greater number of samples during freshet and as such could not be used to calculate the nitrogen export. For all mines, the inorganic nitrogen loading for each sampling day was calculated and plotted. The annual load was then determined by the area under the curve (planimeter).

2 KOOTENAY COAL FIELDS AND POTENTIAL NUTRIENT RELEASES

The Kootenay coal fields are located in southeastern British Columbia. The area is mountainous lying within the Front Ranges of the Rocky Mountains at an elevation range of 1000 m to 2500 m above sea level.

The climate is best described as dry, sub-humid, and microthermal (snow) continental with hot to warm summers varying with elevation. Cold winters are dominated by dry continental Arctic air masses from northern regions. Precipitation is heaviest from late fall through the winter to early spring. Annual precipitation is about 700 mm. Mean monthly air temperature ranges from about -10°C in winter to about 16°C in summer. Air temperatures below 0°C are normally experienced during November through April. About 40% of the annual precipitation in valley areas falls as snow during this same time period.

The Kootenay coal fields are drained primarily by three large water systems - the Elk River, the Fording River and Michel Creek. Numerous small systems drain the mountainous areas (Figure 2).

Maximum stream flows occur in May and June due to spring snowmelt. Flows decline steadily during the summer and fall reaching a minimum in winter.

Large-scale surface and underground coal mining began in the Kootenay coal fields in 1967 with Kaiser Resources Ltd. (now Westar Mining Ltd.-Balmer) followed by Fording Coal Ltd. in 1971, Byron Creek Collieries Ltd. in 1976, Crows Nest Resources Ltd.-Line Creek Mine in 1981 and Westar Mining Ltd.-Greenhills in 1982. Historical coal and waste rock production since 1980 for the five mines are shown in Figure 3. The Westar-Balmer mine produces the most coal followed by Fording, Westar-Greenhills, Crows Nest Resources-Line Creek, and Byron Creek Collieries. Annual coal production at each mine has fluctuated over the last five years but cumulative production has increased. In 1985, raw coal production reached about 23 million tonnes. Similarly, the total quantity of rock mined has increased and in 1985 reached almost 100 million bank cubic metres.

There are several potential sources of nutrients from the mines in the Kootenay coal fields. These include fertilizers used in mine and

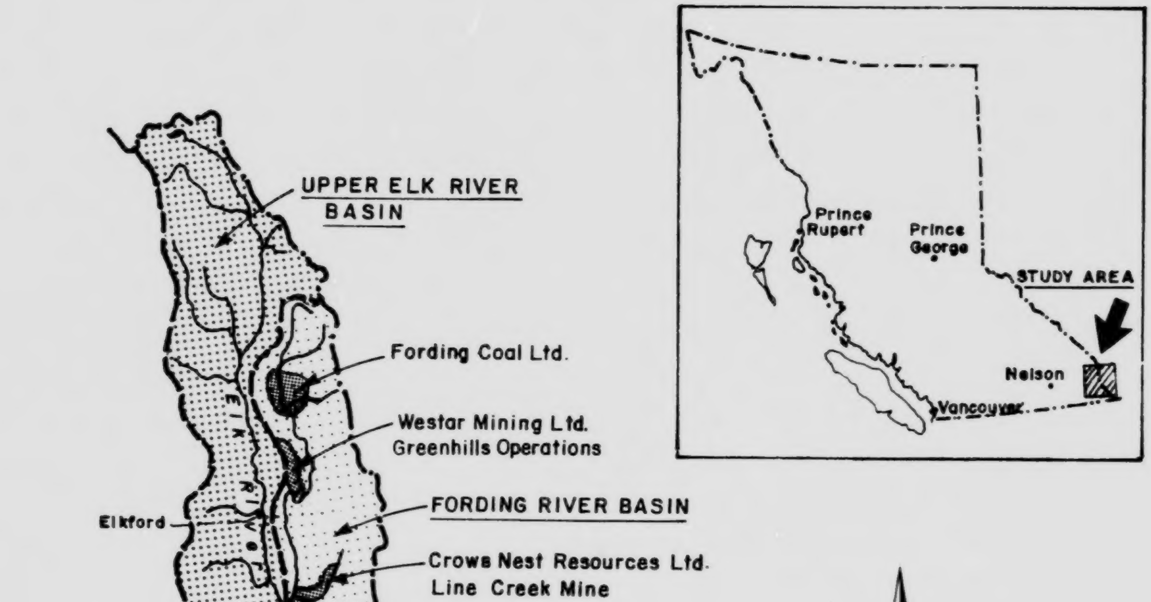

UPPER ELK RIVER BASIN
Fording Coal Ltd.
Westar Mining Ltd. Greenhills Operations
FORDING RIVER BASIN
Crows Nest Resources Ltd. Line Creek Mine
MICHEL CREEK BASIN
Westar Mining Ltd. Balmer Operations
Coleman Collieries
Byron Creek Collieries Ltd.
FLATHEAD RIVER BASIN
Proposed Sage Creek Coal Project
LOWER ELK RIVER BASIN
Elkford
Sparwood
Hosmer
Fernie
Elko
Elko Dam
Kootenay River
Elk River
Flathead River
Wigwam R.
ALBERTA
BRITISH COLUMBIA
WASHINGTON
Prince Rupert
Prince George
STUDY AREA
Nelson
Vancouver
N

FIGURE 2 DRAINAGE BASINS IN SOUTHEASTERN BRITISH COLUMBIA

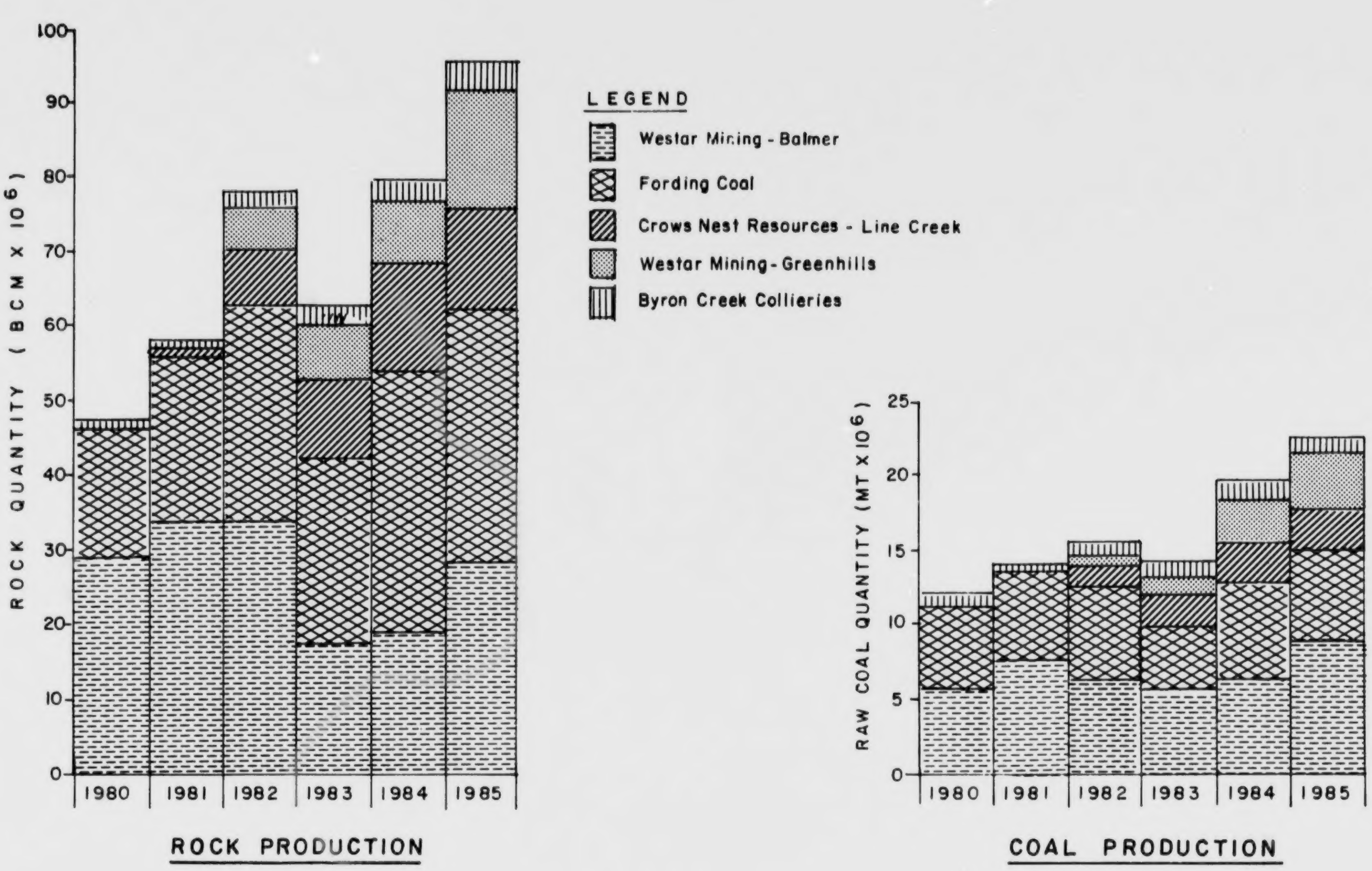


FIGURE 3 ANNUAL ROCK AND COAL PRODUCTION FOR KOOTENAY COAL FIELDS MINES

exploration site reclamation, domestic sewage discharged to surface waters or to the ground, leachates from coal and waste rock weathering, and residual explosives. Residual explosives are expected to be the largest source of nitrogen based on previous work in the region.

The principle nitrogen compound in explosives used at the coal mines is ammonium nitrate. This compound is extremely soluble in water and disassociates into ammonium and nitrate ions. The nitrogen content varies from mine to mine, but is about 33% N by weight for ANFO and about 25% N for slurry. Nitrogen losses to water from explosives may occur through contact between water and explosive prior to detonation or water and explosive residuals produced during detonation.

Historical annual explosive use from 1980 to 1985 for each mine in the Kootenay coal fields is shown in Figures 4 and 5. In general, ANFO use has been predominant at both Westar operations, Crows Nest Resources-Line Creek mine and Byron Creek Collieries. ANFO is preferred since it is cheaper; the unit costs for ANFO and slurry are about equal but more slurry explosive is required per blasthole. Slurry explosive is not as soluble as ANFO, and, therefore, is preferred in wet blasting conditions. The Fording coal mine used more slurry explosive than ANFO from 1980 to 1982, but more ANFO than slurry from 1983 to 1985. This reflects the development of the Eagle Mountain mining project at the Fording Mine in 1983 and the gradual phasing out of the Clode Creek and Greenhills pits. The former is a ridge top surface mine with dry blasting conditions while the Clode and Greenhills pits were valley bottom mines with wet conditions.

In 1985, approximately 31 300 tonnes of ANFO explosive and 5 410 tonnes of slurry explosive were used in the Kootenay coal fields. Using the predictive formula developed by Pommen, and assuming a 33% N content in ANFO and a 25% N content in slurry, about 180 tonnes of nitrogen could be released to receiving streams in the region. Actual water quality data for each mine must be examined to determine if this potential release was realized.

In this report, the water quality data are reviewed briefly for the Byron Creek Collieries and Westar-Greenhills mines to estimate nitrogen export. Data for the Fording Coal mine is examined in more detail to

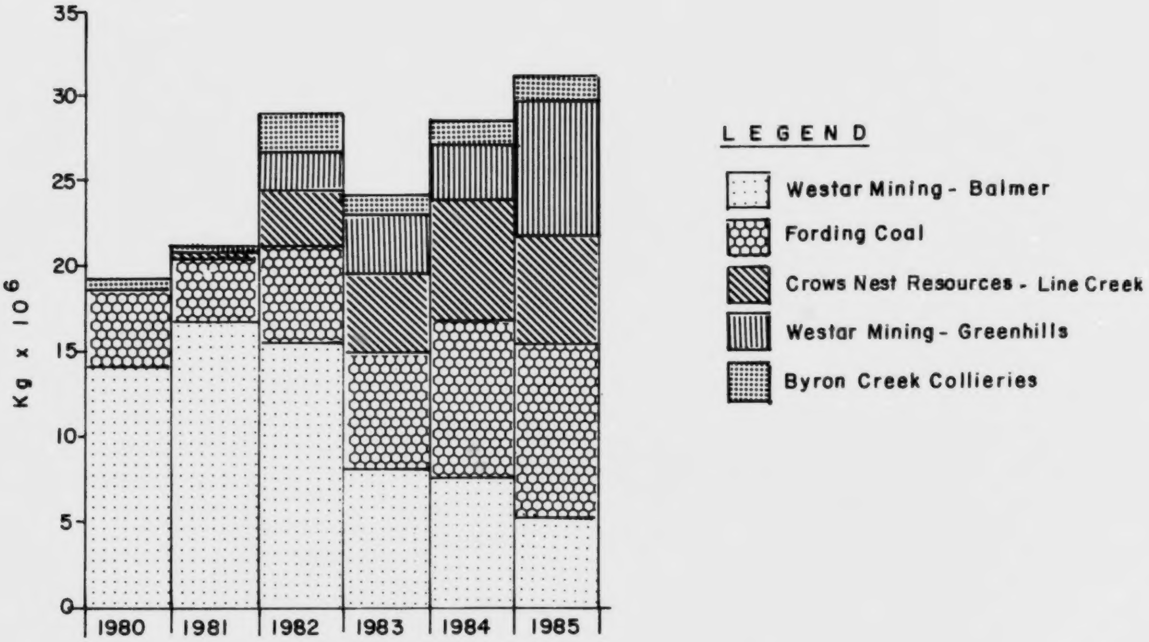


FIGURE 4 ANNUAL ANFO EXPLOSIVE USE FOR KOOTENAY COAL FIELDS MINES

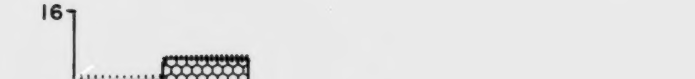


FIGURE 5 ANNUAL SLURRY EXPLOSIVE USE FOR KOOTENAY COAL FIELDS MINES

determine nitrogen export and changes in nitrogen release from mine sources since the Pommen study. Finally, the Crows Nest Resources-Line Creek and Westar-Balmer mines data are examined in even greater detail as more data are available (company data augmented by information collected specifically for this study). Contributions from various sources and phosphorus export are also examined for these latter two mines.

3 NUTRIENT EXPORT FROM KOOTENAY COAL MINES

3.1 Byron Creek Collieries (1983-85)

The Byron Creek Collieries mine is located approximately 25 km south of Highway No. 3 or 10 km east of Sparwood in the Michel Creek Valley. The mine is at the north end of Coal Mountain, bounded by Corbin Creek on the north and east and Michel Creek on the west (Figure 6). This is a surface mine employing a typical truck and shovel operation. Overburden or spoil from the mining operation is dumped over the west side of the mountain. However, permission has been obtained to dump overburden into the Corbin Creek valley, forming a flow-through rock drain.

Prior to May 1986, raw coal was simply screened, washed in a jig, and dried in a centrifugal dryer. A new preparation plant has been constructed and will utilize a flotation process to clean the coal. This new plant has a capacity of two million tonnes per year of clean coal. The present production level is about one million tonnes per year.

The Byron Creek Collieries mine used the least amount of explosives of any mine in the Kootenay coal fields. Only 555 000 kg (as N) of ANFO and 2 600 kg (as N) of slurry was used in 1985. The low slurry explosive use relative to ANFO reflects the dry blasting conditions encountered at the mine.

Water quality and flow data collected by the company were examined to determine the inorganic nitrogen release. Phosphorus data were unavailable.

Data from Corbin and Michel Creeks upstream and downstream of the mine were assessed to obtain total inorganic nitrogen loadings from the mine site. Flow data were collected by the company at the Corbin Creek upstream and downstream sites for 1983 and 1984. Water Survey of Canada operated a flow station on Michel Creek upstream of the mine from late April to early October in 1984 and 1985. This included the freshet period when most of the nutrient loadings would be expected from the minesite. To obtain flows for Michel Creek upstream of the mine at other times during 1985, the flow in Corbin Creek downstream was multiplied by the mean ratio of recorded flows in Michel Creek upstream to Corbin Creek downstream. The flow at the Michel Creek downstream water quality site was estimated by adding the Michel Creek

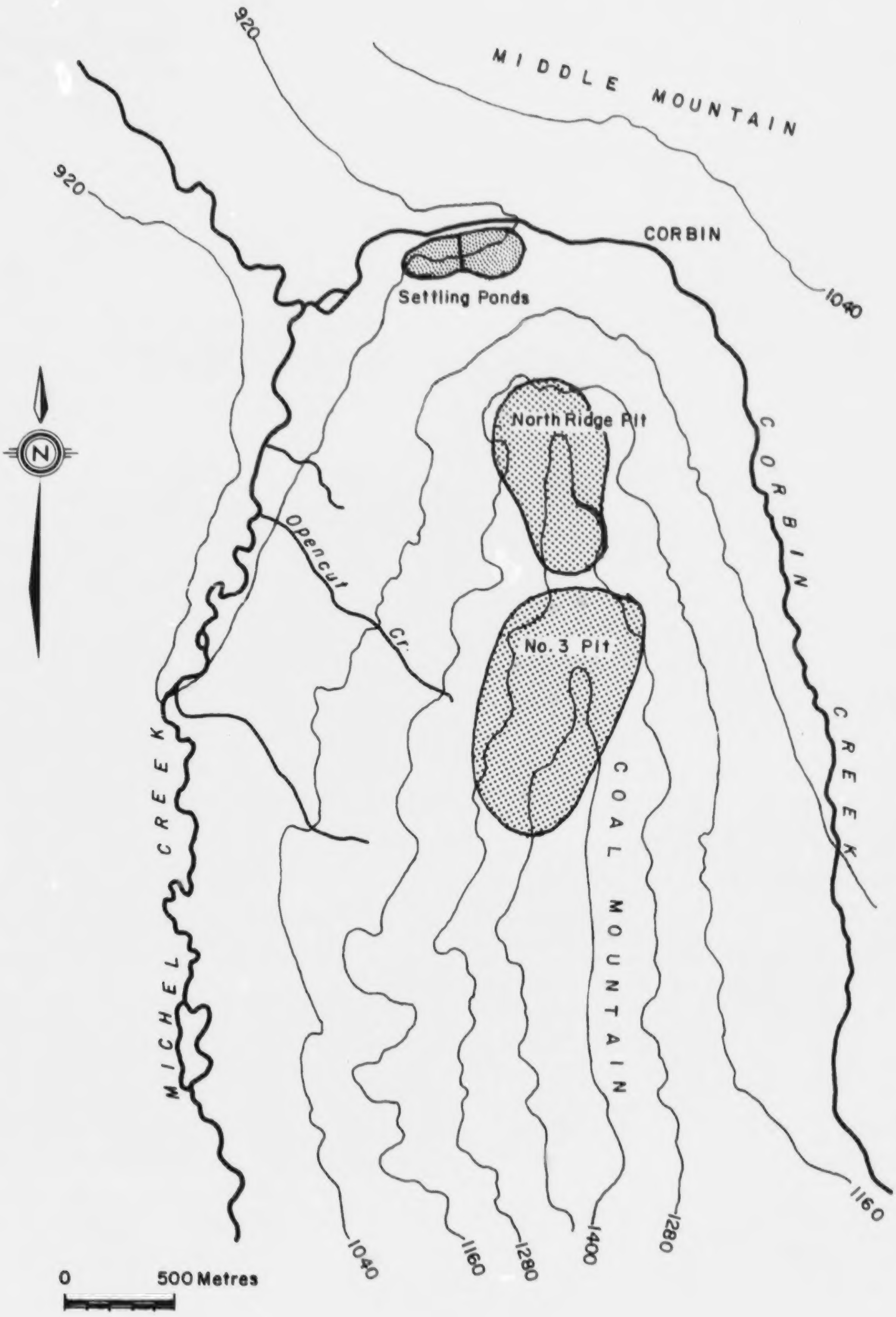

MIDDLE MOUNTAIN
920
920
CORBIN
1040
Settling Ponds
North Ridge Pit
No. 3 Pit
Opencut Cr.
CORBIN CREEK
MICHEL CREEK
COAL MOUNTAIN
1040
1160
1280
1400
1280
1160
0
500 Metres
N

FIGURE 6 BYRON CREEK COLLIERIES DRAINAGE SYSTEM

upstream and Corbin Creek downstream results. Since the Michel Creek downstream site is below the confluence with Corbin Creek, and virtually all mine drainage is released to Corbin Creek, the latter stream was used to calculate the export of nurtients from the mine. Nutrient export using Michel Creek data was calculated as a check of the Corbin Creek results.

Water quality data were available on a monthly basis from 1983 to 1985. The sum of nitrate, nitrite, and ammonia nitrogen was multiplied by the flow to obtain the total inorganic nitrogen loading. As flow data for the Corbin Creek sites were not collected on the same day as the water quality samples, flows for days closest to the sampling days were used to calculate loadings. A summary of the data is presented in Table 1. All concentration, flow, and inorganic loading data may be found in the separate Appendix report.

In general, nitrogen concentrations downstream of the Byron Creek mine were low, the maximum nitrate concentration found in receiving waters downstream was 0.504 mg/L. Maximum loadings occurred in the spring coincident with maximum flows. Loadings downstream were higher than those upstream which suggests the mine was a source of inorganic nitrogen (Table 2). The total amount of inorganic nitrogen exported from the mine amounted to approximately 1170 kg in 1984 and 1400 kg in 1985 or only 0.3% and 0.2% of the explosive used; that is, less than half that predicted by the Pommen formula. The calculated nutrient export using Michel Creek data was even less than that determined using Corbin Creek results.

3.2 Westar Mining-Greenhills Operation (1984-85)

Westar Mining Ltd.-Greenhills Operation straddles a rich coal belt known as the Greenhills Range located 45 km north of Sparwood. Elevations at the site range from 1 500 meters at the coal load-out area to 2 300 meters within the pit. Coal deposits have been estimated at more than 125 million clean tonnes of coal, approximately 50 million tonnes will be mined during the 20 year life of the mine.

Coal is obtained from up to 26 coal seams using a fully integrated truck and shovel surface mining operation. Both thermal and metallurgical coal are produced from the 1.8 million tonnes per year heavy media, single

TABLE 1 SUMMARY OF BYRON CREEK COLLIERIES RECEIVING WATER NITROGEN DATA

RECEIVING WATERS	YEAR	NH_3/NH_4 (mg/L) Range (Mean)	NO_3 (mg/L) Range (Mean)	NO_2 (mg/L) Range (Mean)	Flow (m^3/s) Range (Mean)	INORG. N LOADING (kg/d) Range (Mean)	NO. OF SAMPLES		
							NH_3/NH_4	NO_3	NO_2
Corbin Creek									
- upstream site	1983	< 0.01-0.02 (0.016)	0.002-0.060 (0.017)	< 0.002-0.007 (0.003)	0.024-1.03 (0.253)	0.034-2.31 (0.748)	10	6	10
	1984	< 0.01-0.17 (0.034)	< 0.001-0.016 (0.003)	< 0.003-0.007 (0.004)	0.015-0.486 (0.100)	0.025-0.798 (0.256)	12	12	12
	1985	< 0.01-< 0.01 (< 0.01)	0.001-0.007 (0.004)	< 0.003-0.005 (0.003)	0.027-0.660 (0.014)	0.030-1.66 (0.716)	12	12	12
- downstream site	1983	< 0.01-0.11 (0.034)	0.002-0.327 (0.137)	< 0.002-0.008 (0.0038)	0.043-1.95 (0.358)	0.220-48.7 (6.22)	10	10	10
	1984	< 0.01-0.04 (0.014)	0.003-0.366 (0.086)	< 0.003-0.113 (0.016)	0.036-1.07 (0.263)	0.285-18.25 (3.66)	12	12	12
	1985	< 0.01-0.08 (0.028)	0.002-0.407 (0.147)	< 0.003-0.011 (0.004)	0.031-1.40 (0.294)	0.316-19.72 (4.205)	12	12	12
Michel Creek									
- upstream site	1983	< 0.01-0.12 (0.0333)	0.002-0.023 (0.0079)	< 0.002-0.010 (0.0034)			12	7	12
	1984	< 0.01-0.03 (0.0127)	< 0.001-0.013 (0.0162)	< 0.003-0.006 (0.0037)	0.09-2.52 (0.4387)	0.14-3.70 (0.9987)	11	11	11
	1985	< 0.01-0.07 (0.0267)	< 0.003-0.065 (0.0104)	< 0.003-0.004 (0.0031)	0.11-7.57 (1.2356)	0.27-38.6 (5.325)	12	12	12
- downstream site	1983	< 0.01-0.14 (0.0300)	0.001-0.504 (0.0930)	< 0.002-0.007 (0.043)			12	11	12
	1984	< 0.01-0.03 (0.0118)	0.003-0.151 (0.0341)	< 0.003-0.015 (0.0054)	0.14-3.14 (0.7209)	0.24-18.28 (3.583)	11	11	11
	1985	< 0.01-0.04 (0.0175)	0.003-0.164 (0.0453)	< 0.003-0.008 (0.0036)	0.11-7.57 (1.2339)	0.44-28.1 (6.49)	12	12	12

TABLE 2 INORGANIC NITROGEN EXPORT FROM BYRON CREEK COLLIERIES

	1984	1985
ANNUAL INORGANIC N LOADING (kg·N)		
Michel Creek upstream	340	1,930
Michel Creek downstream	1,100	2,360
Net Increase	760	430
Corbin Creek upstream	74	130
Corbin Creek downstream	1,240	1,530
Net Increase	1,170	1,400
Total Export from Mine	1,170	1,400
EXPLOSIVE USE (kg·N) ANFO	410,000	555,000
Slurry	1,000	2,600
Total	411,000	557,600
ACTUAL N EXPORT AS % EXPLOSIVE	0.3%	0.2%
PREDICTED N EXPORT FROM MINE kg·N ANFO	4,100	5,600
Slurry	60	160
Total	4,160	5,760
PREDICTED N EXPORT AS % EXPLOSIVE	1.0%	1.0%
% ACTUAL N EXPORT OF PREDICTED	28%	24%

circuit preparation plant. Clean coal is transported via rail to Roberts Bank near Vancouver for shipment overseas.

The Greenhills mine uses a significant amount of explosives. For example, in 1985, the Greenhills mine used the second greatest amount of ANFO of all the mines in the Kootenay coal fields. Only small amounts of slurry explosives were employed due to the dry blasting conditions associated with ridge top mining.

Numerous small streams drain the mining property to feed the major rivers, the Fording River on the east and south and the Elk River on the west (Figure 7). Because their watersheds are actively mined, the most important of these are Porter, Cataract, Greenhills, and Thompson Creeks. Water quality and flow data collected by the company were examined to determine the inorganic nitrogen released from this mine in 1984 and 1985. Ten to sixteen sets of data were collected each year from these streams. In general, sampling was conducted weekly from April to July and monthly the rest of the year. Thus, sampling frequency was concentrated during the higher flow freshet period. Flow readings were recorded at the time of sampling. No phosphorus data were available for these streams.

A summary of inorganic nitrogen concentration, loading, and flow for the four major discharges from this mine are presented in Table 3. In general, nitrogen concentrations were low with the maximum nitrate concentration of 1.34 mg/L found in Greenhills Creek. Maximum loadings occurred in the spring coincident with maximum flows. A listing of all available data is presented in the separate Appendix report.

The inorganic nitrogen export from the Greenhills mine was calculated by summing the load carried by each of the major creeks (Table 4). These values of 2 079 kg and 3 645 kg in 1984 and 1985, respectively, represented the maximum loss of explosives nitrogen since background nitrogen concentrations of the streams are unknown. However, the total nitrogen export from the mine area represented only 0.2% and 0.1% of the explosive used in 1984 and 1985 compared to about 1% predicted using the Pommen formula. The actual nitrogen export from the Greenhills mine was only 19% and 13% of the predicted values for 1984 and 1985, respectively.

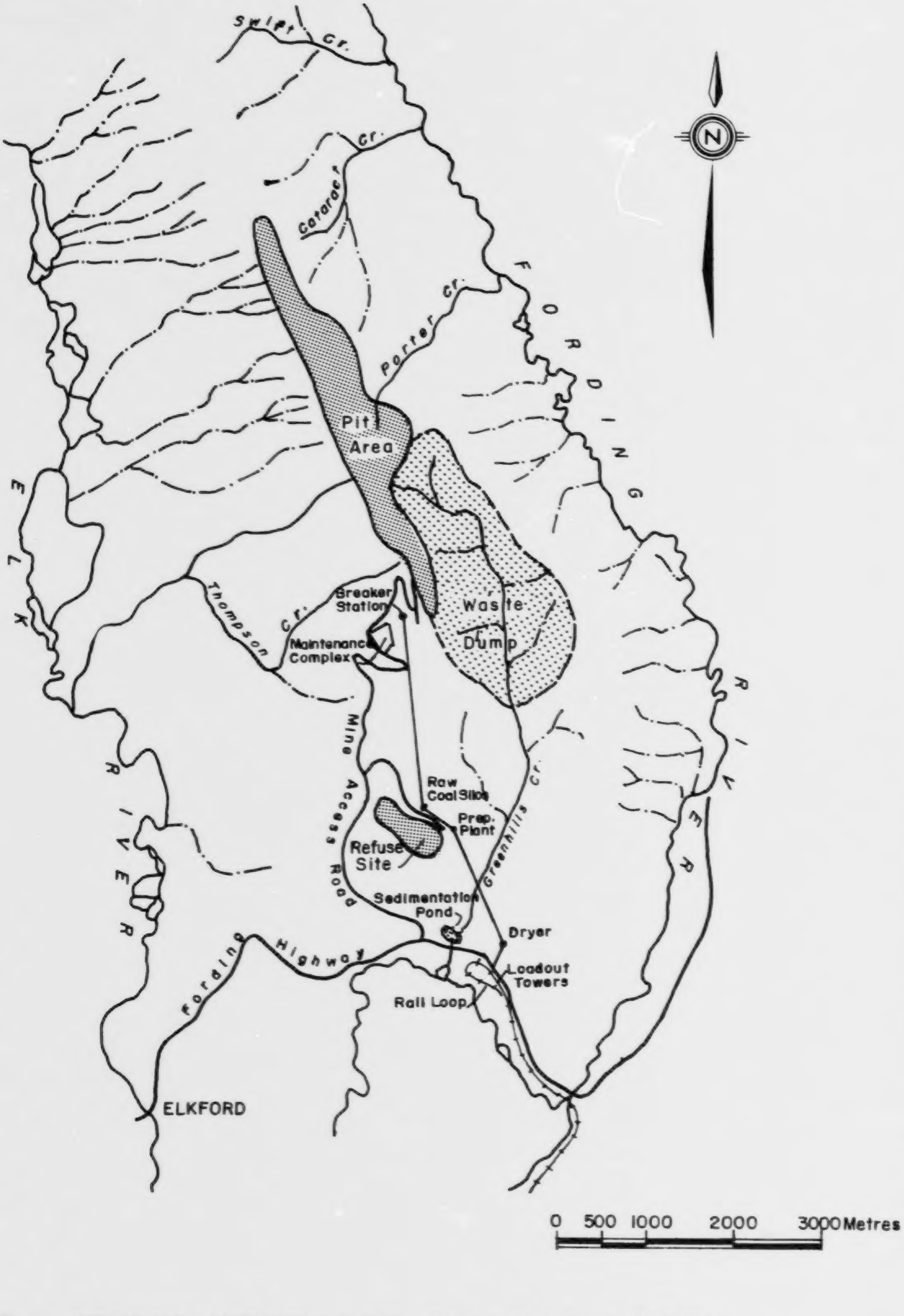

Swift Cr.
Cataract Cr.
Porter Cr.
FORDING RIVER
N
Pit Area
Waste Dump
ELK RIVER
Thompson Cr.
Breaker Station
Maintenance Complex
Mine Access Road
Raw Coal Silos
Prep. Plant
Greenhills Cr.
Refuse Site
Sedimentation Pond
Dryer
Loadout Towers
Rail Loop
Fording Highway
ELKFORD
0 500 1000 2000 3000 Metres

FIGURE 7 WESTAR-GREENHILLS DRAINAGE SYSTEM

TABLE 3 SUMMARY OF WESTAR-GREENHILLS OPERATIONS EFFLUENT NITROGEN DATA

EFFLUENT STREAMS	YEAR	NH_3/NH_4 (mg/L) Range (Mean)	NO_3 (mg/L) Range (Mean)	NO_2 (mg/L) Range (Mean)	Flow (m^3/s) Range (Mean)	INORG. N LOADING (kg/d) Range (Mean)	NO. OF SAMPLES		
							NH_3/NH_3	NO_3	NO_2
Porter Creek	1984	ND-0.252 (0.075)	ND-0.700 (0.347)	0.001-0.022 (0.004)	0.007-0.190 (0.108)	0.155-11.36 (3.40)	16	17	16
	1985	0.012-0.235 (0.080)	0.010-0.635 (0.324)	0.001-0.016 (0.003)	0.015-0.835 (0.134)	0.136-11.90 (4.07)	14	18	15
Cataract Creek	1984	ND-0.237 (0.062)	ND-0.710 (0.378)	ND-0.006 (0.003)	0.016-0.303 (0.138)	2.86-6.62 (4.70)	15	16	15
	1985	0.009-0.140 (0.066)	0.100-1.19 (0.427)	0.001-0.05 (0.007)	0.009-0.233 (0.072)	0.152-24.30 (5.882)	11	12	11
Greenhills Creek	1984	0.012-0.151 (0.075)	0.160-0.640 (0.370)	0.001-0.027 (0.01)	NF-0.263 (0.150)	0.441-18.1 (6.259)	10	11	10
	1985	0.005-0.50 (0.097)	0.045-1.34 (0.373)	0.001-0.095 (0.012)	NF-0.348 (0.131)	0.036-11.02 (5.023)	16	18	18
Thompson Creek	1984	ND-0.260 (0.113)	ND-0.755 (0.359)	ND-0.026 (0.004)	0.008-0.178 (0.078)	0.183-8.18 (2.866)	16	17	16
	1985	0.020-0.240 (0.088)	0.100-0.575 (0.274)	0.001-0.017 (0.004)	0.011-0.223 (0.0972)	0.234-12.37 (3.341)	16	18	15

ND - nondetectable
NF - no flow

TABLE 4 INORGANIC NITROGEN EXPORT FROM WESTAR-GREENHILLS

	1984	1985
ANNUAL INORGANIC N LOADING (kg·N)		
Greenhills Creek	368	416
Porter Creek	485	1,010
Cataract Creek	816	1,659
Thompson Creek	410	560
Total Export from Mine	2,079	3,645
EXPLOSIVE USE (kg·N) ANFO*	1,067,000	2,610,000
Slurry**	800	25,000
Total	1,067,800	2,635,000
ACTUAL N EXPORT AS % EXPLOSIVE	0.2%	0.1%
PREDICTED N EXPORT FROM MINE kg·N ANFO	10,670	26,100
Slurry	48	1,500
Total	10,720	27,600
PREDICTED N EXPORT AS % EXPLOSIVE	1.0%	1.0%
% ACTUAL N EXPORT OF PREDICTED	19%	13%

* assuming ANFO 33% nitrogen
** assuming slurry 25% nitrogen

3.3 Fording Coal

The Fording Coal Limited mine is located near the headwaters of the Fording River, a tributary of the Elk River. The closest settlement is Elkford located 30 km south of the mine on the Elk River. The mine straddles the Fording River between Henretta and Kilmarnock Creeks. The Fording Valley runs north-south with Eagle and Turnbull Mountains to the east and the Greenhills Range to the west (Figure 8).

The operations employ both truck/shovel and dragline mining techniques in multiple seam pits. The mine initially entered production to supply market demands for low volatile metallurgical coal. However, in the early 1980's Fording diversified to produce a variety of product coals; thermal coal, weak coking coal, high-volatile metallurgical coal, mid-volatile metallurgical coal and low-volatile (standard blend) metallurgical coal.

Since 1980, mining activities have shifted from the west to the east side of the Fording River. The Eagle Mountain Project commenced in the spring of 1983 in order to maintain coal production levels. The project involves several new open pits on the peaks and ridge tops of Eagle Mountain. Eagle Mountain will be the major mining area for Fording's truck/shovel fleet for the next 36 to 50 years.

The present dragline mining activities are being carried out in Pit 3 which is located in the Greenhills mining area. The overburden generated at the Greenhills pit is dumped on the west side of the Fording River. The overburden from the Eagle Mountain Pit is dumped over the east face of Brownie Ridge, as well as the upper portions of the Clode, Blackstone and Blackrill drainage basins. All fine refuse from the plant is deposited into the South Tailings Pond.

Coal is transported from the various pits by truck to the plant site. The coal then moves through the breaker, the preparation plant, the dryer and finally to the load-out area. From here the coal is transported to Roberts Bank in unit rail cars. Production rates at Fording Coal Ltd. have increased from 3 million to 5 million tonnes of clean coal per year.

Explosive use at Fording began in 1971. An average of 10 000 tonnes per year were used from 1976 to 1980. This amounted to about 2 500 tonnes per year of nitrogen. The average powder factor or blasting

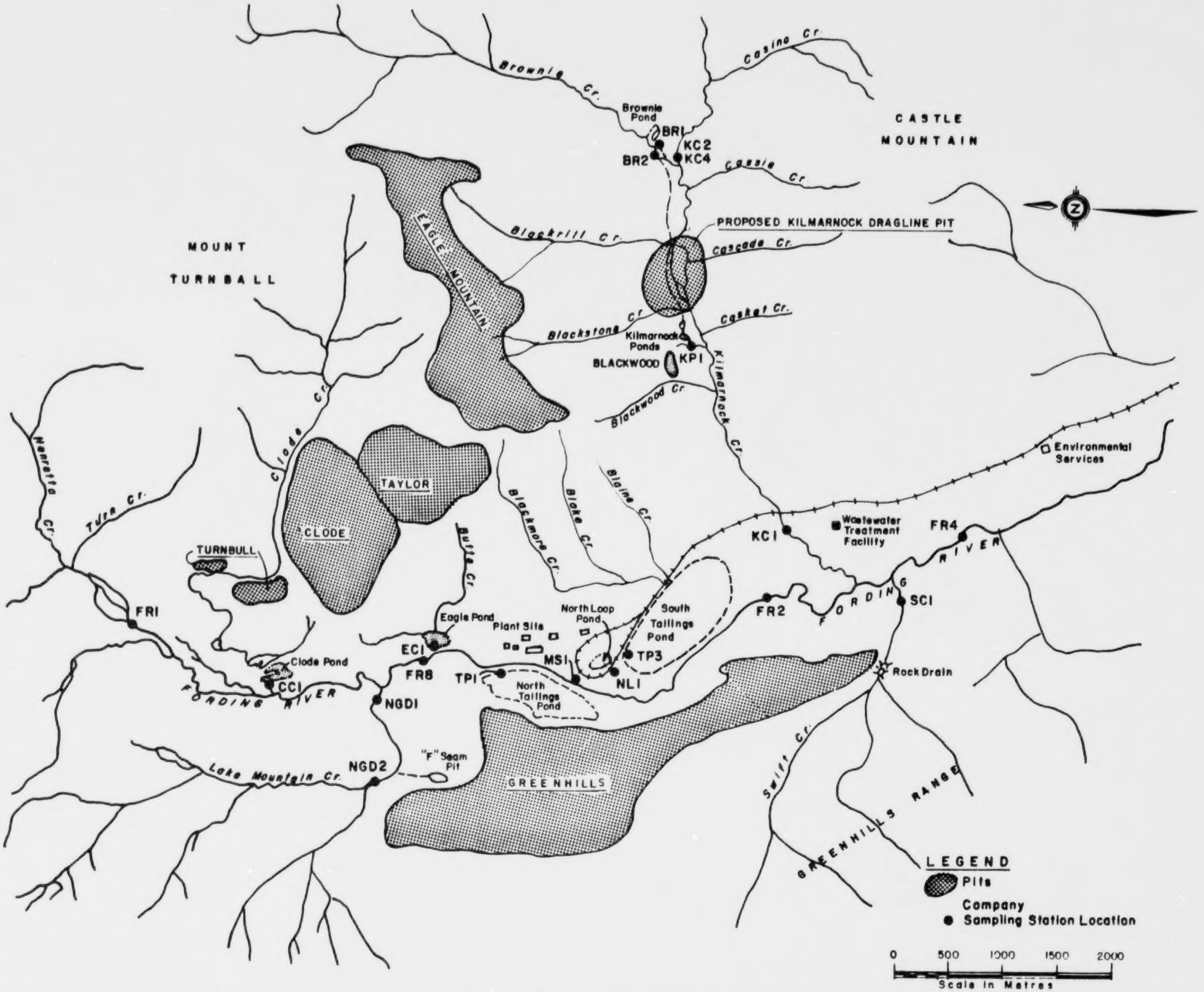

Brownie Cr.
Casino Cr.
Brownie Pond
BR1
BR2
KC2
KC4
Cassie Cr.
CASTLE MOUNTAIN
Z
PROPOSED KILMARNOCK DRAGLINE PIT
Blackrill Cr.
Cascade Cr.
MOUNT TURNBALL
EAGLE MOUNTAIN
Blackstone Cr.
Casket Cr.
Kilmarnock Ponds
KP1
BLACKWOOD
Blackwood Cr.
Kilmarnock Cr.
Environmental Services
Henretta Cr.
Tyre Cr.
Clode Cr.
TAYLOR
CLODE
Blackmore Cr.
Blake Cr.
Blaine Cr.
KC1
Wastewater Treatment Facility
FR4
RIVER
TURNBULL
Butte Cr.
FR1
Eagle Pond
Plant Site
North Loop Pond
South Tailings Pond
FR2
FORDING
SC1
Clode Pond
EC1
MS1
TP3
CC1
FR8
TP1
NL1
Rock Drain
FORDING RIVER
NGD1
North Tailings Pond
"F" Seam Pit
Lake Mountain Cr.
NGD2
GREENHILLS
Swift Cr.
GREENHILLS RANGE
LEGEND
Pits
Company Sampling Station Location
0
500
1000
1500
2000
Scale in Metres

FIGURE 8 FORDING COAL DRAINAGE SYSTEM

factor for 1971 to 1979 was 0.8 kg of explosives per bank cubic meter of rock. Slurry explosives were used almost exclusively from 1976 to 1980 because of wet blasting conditions in the pit.

From 1980 to 1985 powder factors dropped annually. In 1981, the powder factor was 0.68 kg/BCM and by 1985 the powder factor dropped further to 0.41 kg/BCM. During this time period an average of 14 000 tonnes of explosives per year were used containing 3 800 tonnes per year of nitrogen. In 1986 the powder factor rose slightly to 0.44 kg/BCM. From 1987 to 1991 powder factors are expected to rise to approximately 0.53 kg/BCM. Slurry explosive utilization has decreased to 26.5% by weight in 1985. The reduced slurry explosive consumption resulted from drier blasting conditions in the Eagle Mountain pits.

Since 1979-80, other changes in blasting practices at Fording Coal have occurred. The implementation of a larger drill pattern, smaller but more frequent blasts, polyethylene liners in wet holes, and better housekeeping practices to minimize explosive spills at the explosive plant site are all changes that would be expected to reduce the overall nitrogen release from the mine.

3.3.1 **Historical Export of Nitrogen (1979-80).** According to Pommen (1983) about 130 tonnes per year of nitrogen were released from the mine to the Fording River in 1979-80. Of this, about 80 tonnes per year were discharged via surface streams draining the mine property and 50 tonnes per year were released to groundwater. Pommen used water quality and flow data in the Fording River upstream and downstream of the mine to calculate the total nitrogen export. He concluded 95% of the nitrogen discharged from the mine was derived from the nitrogen used in explosives. The high nitrogen losses appeared to correlate with the increased use of slurry explosive in wet blasting conditions. About 1% to 2% of the nitrogen in the explosives was lost when loading wet blast holes with slurry explosives; and this may have accounted for 15%-30% of the nitrogen export from the mine. However, nitrogen continued to leach from fresh mine spoil for at least one year or more. Pommen found that the total nitrogen export from the mine was equivalent to about 6% of the nitrogen in the explosives used during the study period.

3.3.2 **Projected Nitrogen Export (1978-91).** Fording Coal Limited estimated the annual export of inorganic nitrogen from the mine for the period from 1978 to 1991. These estimations were based on the type of explosive used, the nitrogen content in the explosives and a nitrogen loss factor of 6% for slurry and 1% for ANFO as recommended by Pommen (1983). The annual nitrogen losses from Fording as predicted using Pommen's formula are shown in Table 5. Fording calculated that about 830 tonnes N was released from the mine between 1980 and 1985 or approximately 140 tonnes N/yr.

TABLE 5 HISTORICAL AND FUTURE EXPLOSIVES USE AND NITROGEN LOSS AT FORDING COAL, 1978-1991

YEAR	VOLUME TO BLAST (10^6 BCM)	TOTAL EXPLOSIVES REQUIRED (10^6 kg)	POWDER FACTOR (kg/BCM)	EXPLOSIVES TYPE		TOTAL NITROGEN CONTENT IN EXPLOSIVES USED (10^6 kg)	TOTAL NITROGEN LOSS (10^3 kg)
				ANFO %	SLURRY %		
1978*	12.05	10.47	0.87	0.1	99.9	2.62	157.0
1979*	11.97	9.24	0.77	3.6	96.4	2.34	134.7
1980*	17.03	13.55	0.80	3.3	96.7	3.43	198.1
1981*	21.62	15.23	0.70	24.7	75.3	3.34	176.7
1982*	28.34	15.49	0.55	38.7	61.3	4.35	162.2
1983*	24.36	10.72	0.46	63.5	36.5	3.18	78.8
1984*	34.79	15.74	0.45	59.3	40.7	4.62	123.1
1985*	33.79	13.75	0.41	73.5	26.5	4.2	85.0
1986**	37.3	16.12	0.43	78.0	22.0	4.99	93.4
1987**	41.3	17.72	0.43	81.4	18.6	5.55	95.0
1988**	41.03	17.48	0.43	81.0	19.0	5.47	94.5
1989**	40.08	16.99	0.42	77.8	22.2	5.26	98.0
1990**	36.76	15.4	0.42	80.0	20.0	4.81	84.2
1991**	36.28	15.2	0.42	70.0	30.0	4.60	101.2

* based on actual amounts used for these years
** 1985 forecast

Predicted total nitrogen loss to the environment from explosives peaked in 1980 and decreased substantially thereafter. This trend was expected despite an increase in production because of the increased use of ANFO at the minesite and more efficient blasting (as shown by the decreased powder factor from 1978 to 1991). These projections suggest an overall 30% reduction of total nitrogen loss from explosives use from 1982 to 1991.

3.3.3 **Actual Nitrogen Export (1981-85).** Actual effluent and receiving water monitoring data for the Fording Coal mine from 1981 to 1985 are summarized in Table 6. Detailed data sets are found in the separate Appendix report.

Elevated concentrations of nitrogen in the Fording River were first noted during low flows in 1976 and persisted through 1980. The appearance of high concentrations of nitrogen coincided with the increased use of slurry explosives in 1975-76 due to wet blasting conditions. Elevated concentrations of nitrogen species are still found downstream of the mine. Concentrations are much higher in effluents and receiving waters compared to levels previously discussed from the Byron Creek Collieries and Westar-Greenhills mines.

Pommen used actual flow data and nitrogen concentration data for stations upstream and downstream of the mine to determine the export of nitrogen from the mine to receiving waters for his study. For the EP study, data were compiled for 1981 to 1985 from the same sites examined by Pommen.

To calculate loadings in the Fording River, the nitrogen concentrations at Fording River upstream (FR1), Fording River above Kilmarnock Creek (FR2), Fording River downstream (FR4), and flow data from the WSC gauge below Clode Creek between FR1 and FR2 were used. Since flow and concentration data locations are not the same, loadings may be overestimated at FR1 and underestimated at FR2 and FR4.

Nitrogen loadings for Fording River upstream (FR1) and downstream (FR4) and the total nitrogen export from the mine site are shown in Table 7. Quantities of explosive used were provided by Fording Coal Ltd. There are some minor differences between the quantities shown in Table 7 compared to Table 5. The more recent values used in Table 7 were assumed to be correct for this study.

In general, there were high losses of nitrogen from the Fording Coal Mine between 1981 and 1985. In three cases, the export of nitrogen from the mine was overestimated by the Pommen formula, but it was not overestimated to the same extent as for the Byron Creek or Westar-Greenhills mines. In one case (1985), the export of nitrogen was underestimated, and in another case, export was exactly (1983) as predicted by the Pommen formula.

TABLE 6 SUMMARY OF FORDING COAL EFFLUENT AND RECEIVING WATER NITROGEN DATA

EFFLUENTS	YEAR	NH_3/NH_4 (mg/L) Range (Mean)	NO_3 (mg/L) Range (Mean)	NO_2 (mg/L) Range (Mean)	FLOW (m^3/s) Range (Mean)	INORG. N LOADING (kg/d) Range (Mean)	NO. OF SAMPLES		
							NH_3/NH_4	NO_3	NO_2
Clode Creek Pond Decant	1984	< 0.01-0.18 (0.055)	0.32-5.92 (3.474)	0.003-0.031 (0.019)	NF-0.345 (0.090)	0.267-77.18 (31.427)	11	11	11
	1985	< 0.01-0.14 (0.039)	0.165-5.99 (3.802)	< 0.003-0.035 (0.017)	NF-0.295 (0.112)	0.154-83.16 (35.824)	10	10	10
Clode Creek Pond Seepage (south)	1981	< 0.01-2.4 (0.675)	3.4-21.0 (9.475)	0.01-0.02 (0.013)	0.048-0.048 (0.048)	39.9-97.1 (64.550)	4	4	4
	1982	0.03-0.16 (0.078)	0.49-3.94 (2.586)	< 0.001-0.13 (0.027)	0.048-0.048 (0.048)	2.7-16.8 (11.14)	5	5	5
Clode Creek Pond Seepage* (south-west)	1981	< 0.01-0.2 (0.125)	1.3-9.2 (3.775)	< 0.01-0.01 (0.01)	0.076-0.076 (0.076)	6.2-17.1 (25.725)	4	4	4
	1982	0.01-0.19 (0.089)	0.023-5.14 (1.941)	0.001-0.15 (0.026)	0.076-0.076 (0.076)	1.7-34.6 (14.617)	6	6	6
Eagle Pond Supernatant	1981	< 0.01-< 0.01 (< 0.01)	44-140 (92.00)	0.12-10.0 (5.06)			2	2	2
	1982	0.03-0.34 (0.164)	9.15-220 (111.783)	0.035-0.57 (0.162)			8	9	8
	1983	0.01-0.09 (0.040)	47.9-220 (151.271)	0.067-0.20 (0.150)			7	7	7
	1984								
	1985								

CONTINUED...

TABLE 6 (Continued)

EFFLUENTS	YEAR	NH_3/NH_4 (mg/L) Range (Mean)	NO_3 (mg/L) Range (Mean)	NO_2 (mg/L) Range (Mean)	FLOW (m^3/s) Range (Mean)	INORG. N LOADING (kg/d) Range (Mean)	NO. OF SAMPLES		
							NH_3/NH_4	NO_3	NO_2
South Tailings Pond Seepage	1981	0.05-11.0 (2.188)	2.0-31.4 (8.917)	< 0.003-0.65 (0.178)	YEARLY FLOW (x 1000 m^3) 7119.2		6	6	6
	1982	< 0.005-0.3 (0.142)	0.022-6.75 (2.266)	0.006-0.251 (0.091)	4864.0		3	3	3
	1983				3840.3				
	1984				3027.7				
	1985				3994.6				
Swift Creek	1982	< 0.01-0.06 (0.019)	< 0.05-46.5 (5.529)	0.004-0.16 (0.023)	NF-1.702 (0.188)	0.86-81.78 (18.663)	18	18	18
	1983	< 0.01-0.01 (0.010)	0.43-5.29 (2.827)	0.003-0.007 (0.005)	NF-0.712 (0.130)	2.13-13.19 (7.678)	9	9	9
	1984	< 0.01-0.04 (0.014)	0.34-31.5 (6.683)	< 0.003-0.014 (0.005)	0.001-0.280 (0.069)	1.08-13.26 (6.596)	18	19	19
	1985	< 0.01-0.09 (0.025)	0.51-12.7 (5.255)	< 0.003-0.041 (0.008)	NF-0.503 (0.095)	2.20-32.95 (10.874)	10	10	10
Kilmarnock Creek Downstream Site	1983	< 0.01-0.01 (0.01)	0.042-0.182 (0.10)	< 0.003-0.008 (0.004)			7	7	7
	1984	0.001-0.16 (0.030)	0.054-0.68 (0.297)	< 0.003-0.008 (0.004)	NF-1.77 (0.536)	1.51-18.35 (5.913)	9	9	9
	1985	< 0.01-0.07 (0.026)	0.089-0.91 (0.444)	< 0.003-0.008 (0.004)	NF-0.757 (0.632)	6.67-34.9 (17.981)	9	9	9
Kilmarnock Creek Upstream Site	1983	< 0.01-0.02 (0.013)	0.069-0.147 (0.092)	< 0.003-0.004 (0.003)			4	4	4
	1984	< 0.01-0.03 (0.015)	0.005-0.38 (0.116)	< 0.003-0.003 (0.003)	0.051-1.77 (0.526)	0.10-16.8 (3.467)	12	12	12
	1985	< 0.01-0.07 (0.025)	0.007-0.197 (0.084)	< 0.003-0.006 (0.003)	0.514-0.757 (0.634)	1.28-8.88 (4.246)	11	11	11

TABLE 6 (Continued)

RECEIVING WATERS	YEAR	NH_3/NH_4 (mg/L) Range (Mean)	NO_3 (mg/L) Range (Mean)	NO_2 (mg/L) Range (Mean)	FLOW (m^3/s) Range (Mean)	INORG. N LOADING (kg/d) Range (Mean)	NO. OF SAMPLES		
							NH_3/NH_4	NO_3	NO_2
Fording River Upstream (FR1)	1981	< 0.01-0.3 (0.083)	< 0.01-0.069 (0.027)	< 0.003-0.01 (0.007)	0.263-1.40 (0.655)	0.176-25.4 (10.107)	4	4	14
	1982	< 0.01-0.13 (0.044)	< 0.01-0.337 (0.084)	< 0.001-0.003 (0.003)	0.124-7.97 (2.332)	0.077-50.3 (10.356)	14	12	12
	1983	< 0.01-0.02 (0.011)	0.005-0.038 (0.033)	< 0.003-0.003 (0.003)	0.288-6.60 (1.988)	1.07-22.6 (8.189)	7	7	7
	1984	< 0.01-0.04 (0.024)	0.003-0.106 (0.038)	< 0.003) (0.003)	0.344-5.21 (1.652)	1.40-29.26 (7.446)	7	7	7
	1985	< 0.01-0.12 (0.033)	< 0.003-0.056 (0.016)	< 0.003-0.005 (0.003)	0.340-4.65 (2.12)	0.970-13.55 (5.583)	6	6	6
Fording River Midstream (FR2)	1983	< 0.01-0.11 (0.048)	1.62-12.7 (5.332)	0.003-0.012 (0.007)	0.146-2.31 (0.754)	146.46-325.3 (197.013)	6	6	6
	1984	0.01-0.14 (0.059)	1.36-12.5 (5.792)	0.004-0.023 (0.010)	0.138-5.21 (1.147)	87.46-837.12 (297.96)	19	19	19
	1985	< 0.01-0.24 (0.068)	2.0-11.5 (5.891)	0.003-0.059 (0.012)	0.113-9.95 (2.50)	113.56-1923.59 (734.27)	12	2	12
Fording River Downstream (FR4)	1981	0.009-0.3 (0.024)	0.3-8.60 (3.217)	< 0.006-0.11 (0.024)	0.283-21.8 (3.021)	196.2-917.3 (378.488)	32	32	32
	1982	< 0.01-0.16 (0.043)	1.1-10.48 (3.911)	0.005-0.033 (0.013)	0.124-10.9 (2.242)	79.8-2029.3 (495.648)	54	53	53
	1983	< 0.01-0.06 (0.018)	0.60-6.89 (2.887)	< 0.003-0.022 (0.008)	0.380-8.45 (2.754)	166.8-764.6 (401.106)	16	16	16
	1984	< 0.01-0.07 (0.035)	1.20-10.8 (4.425)	0.004-0.023 (0.010)	0.289-5.21 (1.709)	162.1-704.2 (385.15)	12	12	12
	1985	< 0.01-0.07 (0.030)	1.7-11.0 (4.689)	0.003-0.010 (0.006)	0.340-4.65 (1.960)	81.7-929.27 (438.327)	7	7	7

TABLE 7 INORGANIC NITROGEN EXPORT FROM FORDING COAL MINE

	1981	1982	1983	1984	1985
ANNUAL INORGANIC N LOADING (kg·N)					
Fording River upstream (FR1)	4,138	3,288	2,031	2,054	1,302
Fording River downstream (FR4)	116,299	136,320	82,591	92,145	103,775
Net Export from Mine	112,000	133,000	81,000	90,000	102,000
EXPLOSIVE USE (kg·N) ANFO	1,241,397	1,978,228	2,246,376	3,080,161	3,335,062
Slurry	2,867,047	2,373,842	978,200	1,601,545	910,938
Total	4,108,444	4,352,070	3,224,576	4,681,706	4,246,000
ACTUAL N EXPORT AS % EXPLOSIVE	2.7%	3.0%	2.5%	1.9%	2.4%
PREDICTED N EXPORT FROM MINE kg·N ANFO	12,414	19,782	22,464	30,802	33,351
Slurry	172,022	142,430	58,692	96,093	54,656
Total	184,437	162,212	81,156	126,895	88,007
PREDICTED N EXPORT AS % EXPLOSIVE	4.5%	3.7%	2.5%	2.7%	2.2%
% ACTUAL N EXPORT OF PREDICTED	61%	82%	100%	71%	116%

In general, therefore, the Pommen formula provided a reasonable prediction of nitrogen export from the Fording Coal mine for 1981 to 1985.

3.3.4 Sources of Nitrogen.

In 1979-80, Pommen (1983) collected flow and water quality data from Kilmarnock Creek, Swift Creek, and several effluent discharges such as the south tailings pond supernantant, CIL swamp drainage (bulk explosives plant), the north loop pond decant, the Eagle settling pond, and the Clode pond seepage (Figure 8). The major sources of nitrogen in 1979-1980 were:

1) Clode pit/spoil drainage - 60 tonnes per year;
2) miscellaneous sources to south tailings pond - 35 tonnes per year;
3) CIL swamp drainage - 15 tonnes per year to south tailings pond and 15 tonnes per year to Fording River; and,
4) south Greenhills pit/spoil drainage - 5 tonnes per year to Swift Creek and thence to the Fording River.

The Clode pit/spoil drainage comprised four drainages entering the Clode and Eagle settling ponds. Effluent reached the Fording River via overflow from the ponds during freshet and seepage throughout the year. The Clode pit was developed in the 1970's and mined progressively until August 1981. Intercepted surface drainage and leakage from Clode Creek entered the pit area during the latter period of the mining sequence (coincident with the Pommen study) when the pit floor was below the valley bottom. At that time, elevated levels of nitrogen were released to the receiving environment. The Clode pit/spoil comprised 45% of the nitrogen released to the Fording River in 1979-80.

Water quality and flow data for the Clode and Eagle Ponds from 1980 to 1985 were examined to determine changes in nitrogen loading from the Clode pit/spoil area since 1979-80. Although mining ceased in the Clode pit in 1981, spoil from the Eagle Mountain Taylor pit continues to be dumped into the Clode drainage area. Leachates from this spoil would reach Clode Creek or Eagle settling pond and eventually the Fording River. However, this waste rock has been blasted with ANFO under drier blasting conditions and thus should have resulted in a lower export of nitrogen than during Pommen's study.

Discharges from this source would reach the Fording River via the Clode and Eagle settling pond overflows and seepages. No data were available on the quantity of seepage from the Clode and Eagle settling ponds for 1980-85. Some data were available on the quality of seepage in 1981 and 1982

(Table 6). Using seepage rates obtained by Pommen in 1979-80 and water quality from 1981 and 1982, the inorganic nitrogen export via the Clode Creek seepage was calculated to be 33 and 13 tonnes per year in 1981 and 1982, respectively, compared to 29 tonnes per year in 1979. Releases from this source may have decreased.

Relatively extensive water quality and flow data were available for the Clode Creek decant for 1984 and 1985. Samples were obtained weekly from March to July and monthly at other times. Peak loadings generally occurred in April or May. Annual loadings of inorganic nitrogen were estimated to be 8 and 13 tonnes in 1984 and 1985, respectively, compared to about 29 tonnes in 1979. Loadings from this source appeared to be lower than levels found by Pommen.

The Eagle settling pond has not overflowed since 1983 although substantial losses via exfiltration to groundwater and, thence, to the Fording River are known to occur. Unfortunately, there are no data on seepage quality or quantity and, therefore, the annual export of nitrogen via this source cannot be determined. However, the mean inorganic nitrogen concentration of the pond supernatant from 1981 to 1985 was very high (122 mg/L based on 17 samples) and was, therefore, a likely significant source of nitrogen loading to the river. Over 99% of this inorganic nitrogen was in the nitrate form.

The south tailings pond seepage was the second largest inorganic nitrogen source found during Pommen's 1979-80 study, and contributed about 50 tonnes N/yr or about 40% of the 130 tonnes N/yr estimated to be entering the river as groundwater. The south tailings pond began receiving tailings effluent in April 1979. At that time, water was being lost via seepage to groundwater at the south end of the pond. Groundwater wells were installed at the south end and seepage is now pumped back into the pond. However, some seepage continued to migrate to the Fording River.

The nitrogen losses for 1980-85 were calculated using the net seepage rates as estimated by Fording Coal Limited in the water balance for the south tailings pond. An average total nitrogen content based on mean inorganic nitrogen concentrations in the tailings pond seepage wells, the actual seepage, and seepage return pumps was used in the calculation of the annual export. The nitrogen in the south tailings ponds fluctuated greatly as its source was from a variety of areas and not constant over time. The sources were as follows:

- pit water from Greenhills pit
- nitrogen from Eagle Mountain drainage
- wash plant and dryer water
- Fording River diverted water
- plant site drainage.

The above calculations indicated an annual export of inorganic nitrogen from the south tailings seepage of 60, 41, 32, 25 and 33 tonnes per year for 1981 through 1985, respectively. As such, losses of inorganic nitrogen appeared to be substantially less after 1981 compared to those found in 1979-80.

Pommen calculated approximately 30 tonnes N/yr was exported from the CIL swamp during 1979-80. An estimated 15 tonnes N/yr was discharged to the Fording River, and about 15 tonnes N/yr was discharged to the south tailings pond via diversion ditches and pumping. The source of the nitrogen in the CIL swamp was believed to be from past discharges from the CIL plant. All effluent from the plant and yard went to the swamp just south of the plant. Since 1979, the plant effluent has been discharged to the south tailings pond which eliminated one source of nitrogen to the Fording River. However, the yard drainage continued to flow to the swamp.

In the fall of 1981, Fording Coal Ltd. conducted a comprehensive study of the "out of plant" wash water to ensure that the clean-up procedures were reducing or minimizing the loss of blast material from the outside yard area and eliminating the second source of contamination - yard drainage.
In total, nine locations were monitored during each washdown of the CIL explosives plant yard during spring melt and/or periods of heavy rainfall. Total volume of effluent was measured or estimated. Monitoring results indicated that elevated nitrogen compound concentrations did occur during a washdown of the yard area, however, the actual loading to the CIL swamp area was small. Also, the monitoring indicated that the CIL swamp area has a high capacity to absorb this small quantity of nitrogen and suspended solids as there was some enhanced vegetation growth. The "out of plant" clean-up

procedures were considered to be effective in minimizing the loss of blast material from outside the yard area and, thereby, eliminated this source of contamination to yard drainage and the Fording River.

A comparison of Fording River upstream and downstream of the CIL plant operations during this study indicated river water quality undergoes little detectable change. Therefore, nitrogen loading from the CIL swamp drainage appeared to have been substantially reduced.

In 1979-80, only about 5 tonnes per year of inorganic nitrogen was released to the Fording River via Swift Creek. The source of nitrogen was the south Greenhills pits and spoil piles. In 1982, a rock drain constructed in Swift Creek allowed the creek to flow through the bottom of a waste rock dump. An increase in nitrogen release would be expected as nitrogen blasting residuals were flushed from the drain during its initial years of operation.

Significant water quality and flow data were collected from Swift Creek near its mouth between 1982 and 1985. The company sampled on a weekly basis from March to July and on a monthly basis at other times during the year. High peak loadings and concentrations were found in 1982 shortly after the construction of the rock drain. Mean annual loadings of inorganic nitrogen were 6, 4, 6, and 4 tonnes per year for 1982 through 1985, respectively. Recent loadings of nitrogen from Swift Creek appeared similar to those noted by Pommen in 1979-80.

3.3.5 Sources Summary. Pommen identified and quantified the various nitrogen sources to the Fording River during 1979-80. Limited or no data existed for a number of these same sites for the period 1980-1985. For this reason, a comparison of 1979-80 data to 1980-85 data was made at only a few sites. Also since 1982, Fording pumped pit water to the Fording River under high flow conditions as part of their water management scheme. This could be a significant source of nitrogen to the Fording River in some years (M. Strosher, personal communications). In general, loadings from the Clode Creek seepage, Clode Creek pond decant, south tailings pond seepage and CIL swamp drainage had decreased since the Pommen study. The loadings from Swift Creek in 1980-85 appeared to be similar to those determined by Pommen in 1979-80. No loading data for the 1980-85 period was available for the Eagle

Pond supernatant, a source determined to be important by Pommen. Recently Kilmarnock Creek became a potential source of nitrogen loading. Although total loading from the Eagle Pond and Kilmarnock Creek cannot be quantified and compared for the two time frames, overall nitrogen loadings were suspected to have declined on average because: a) numerous sources of nitrogen have decreased over the years; b) better housekeeping (blasting techniques) has been implemented; and c) drier pit areas were being mined recently. This assessment agrees with the overall estimate of nitrogen export from the Fording Coal mine presented in Section 3.3.3. Calculated export from 1981 to 1985 ranged from 81 tonnes N/yr in 1983 to 133 tonnes N/yr in 1982 with a mean of 104 tonnes N/yr compared to Pommen's finding of 130 tonnes N/yr in 1979-80. The export from 1983 to 1985 was only 91 tonnes N/yr which suggested the total release was decreasing.

3.4 Crows Nest Resources-Line Creek Mine

Crows Nest Resources Limited-Line Creek Coal Mine, has been in operation since 1981. The Line Creek area is approximately 18 km northeast of Sparwood, B.C. The coal lease lies mainly in the Line Creek valley bordered on the east by Horseshoe Ridge and the Rocky Mountain Range which forms the British Columbia-Alberta border; and on the west by the Witsukit Range which separates the Fording River and Line Creek valleys (Figure 9).

The surface mine is located on Line Creek Ridge between No-Name and West Line Creeks. The open pit mine will progress downslope from the initial excavations using the typical deployment of heavy equipment including drills, electric shovels, trucks, loaders and graders.

The preparation plant at full capacity is rated to produce 1.7 million metric tonnes of thermal coal and 1.3 million metric tonnes of metallurgical coal per annum.

Crows Nest Resources is proposing to expand operations at the Line Creek Mine north of the existing mine area along Line Creek Ridge. This expansion has been temporarily halted due to the recent downturn in the coal markets.

The active mining area for the Line Creek mine is drained to the east and south by Line Creek and to the far west by the Fording River. The open pit mine and the overburden dumps directly impact upon No Name Creek and

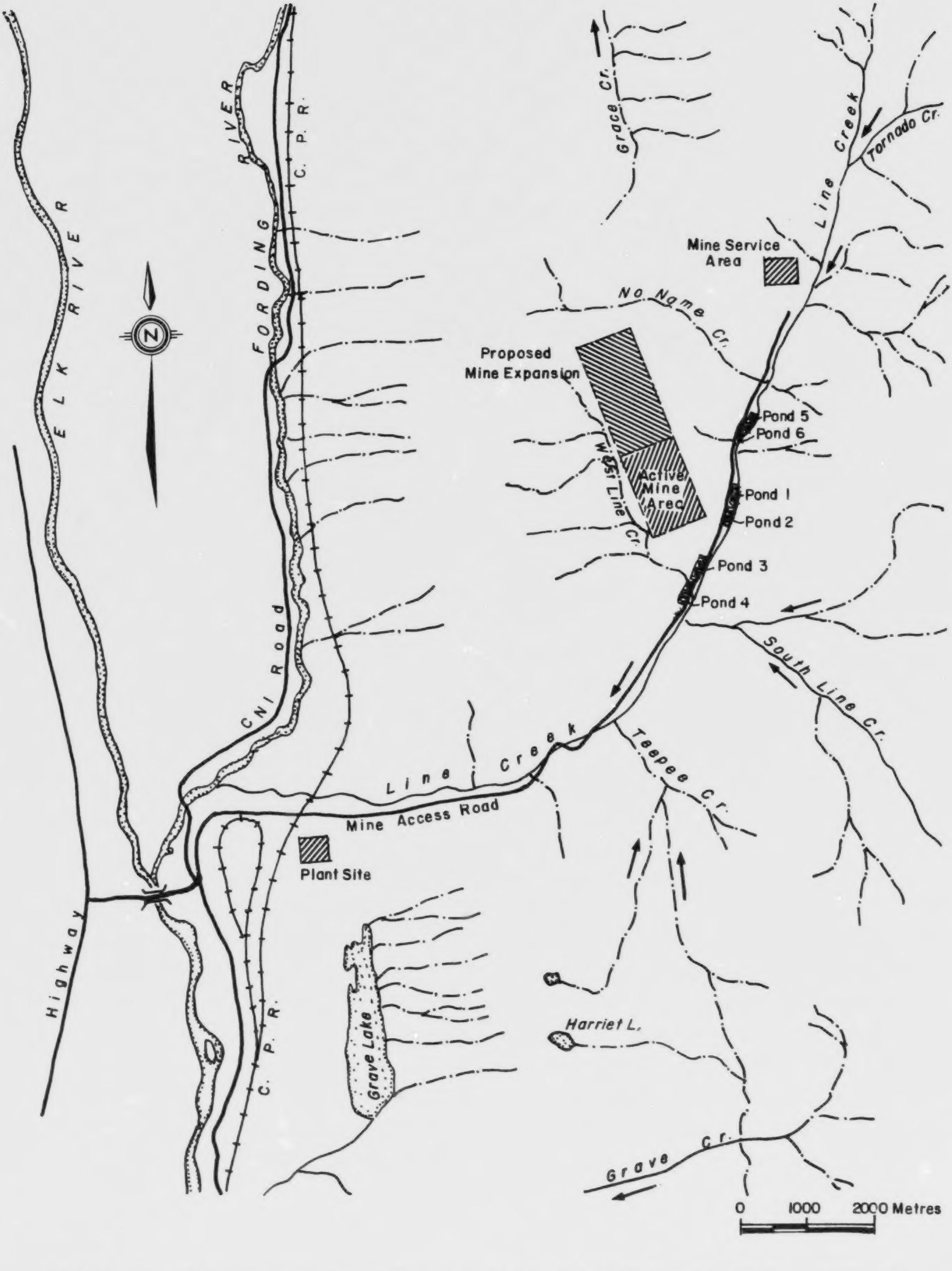

ELK RIVER
FORDING RIVER
C. P. R.
Grace Cr.
Line Creek
Tornado Cr.
Mine Service Area
No Name Cr.
Proposed Mine Expansion
West Line Cr.
Active Mine Area
Pond 5
Pond 6
Pond 1
Pond 2
Pond 3
Pond 4
South Line Cr.
CNI Road
Teepee Cr.
Line Creek
Mine Access Road
Plant Site
Highway
C. P. R.
Grave Lake
Harriet L.
Grave Cr.
0
1000
2000 Metres
N

FIGURE 9 CROWS NEST RESOURCES - LINE CREEK DRAINAGE SYSTEM

West Line Creek which are to the northeast and immediately to the west, respectively, of the mining operation. West Line Creek and No Name Creek both pass through sediment settling ponds prior to discharging into Line Creek. Line Creek eventually flows into the Fording River. The plant site and loadout facilities are located just south of Line Creek near the confluence with the Fording River.

Water quality and flow data were collected by the company and various government agencies from 1981 to 1986 and were used in this section of the report to quantify the inorganic nitrogen released from the Line Creek mine. Water quality data were generally limited to inorganic nitrogen concentrations, however, some data existed on total dissolved phosphorus, soluble reactive phosphorus, and total phosphorus (1985-86). Flow data for other than Line Creek downstream of the operations were limited. Flow data at the Line Creek downstream site were provided by Water Survey of Canada (WSC). Flow data collected by EP were available for No Name Creek for 1985-86. Flows on West Line Creek measured at the site known as Pond #4 discharge from 1982 to 1985 and the data were compiled by the company. No flow data existed for Line Creek upstream of the operations with the exception of four occasions in 1985 when flow was measured by EP staff. Loadings at each site were calculated with the available data. Inorganic nitrogen loadings at the upstream Line Creek site were assumed to be 36% of the downstream site based on the four EP surveys in 1985. Moreover, the drainage area of the upstream Line Creek site was about 35% of the downstream site - in agreement with the proportional loadings of the two sites found in the four EP surveys.

3.4.1 Historical Nitrogen Export. From 1981 to 1984, water quality data was collected by the company primarily at four sites - Line Creek upstream and downstream of the operations, No Name Creek and the Pond #4 decant. Pond #4 decant is the treated effluent from West Line Creek. The samples were collected monthly throughout the year and analyzed for inorganic nitrogen. Flows were determined at the time of sampling at No Name Creek and Pond #4 decant. WSC operates a flow metering station near the mouth of Line Creek at the downstream Line Creek sampling site. Thus, daily flows were available year round at this site. No flows were available for Line Creek upstream of the operations for 1981 to 1984 and, therefore, no loading data were available.

The provincial Waste Management Branch collected samples monthly from Line Creek at the downstream station between 1982 and 1984 and analyzed them for inorganic nitrogen and total dissolved nitrogen. A complete data set is found in the separate Appendix report. A summary of inorganic nitrogen concentration, loading and flow for the two effluents from this mine is presented in Table 8.

The mean ammonia, nitrate and nitrite concentrations for the period 1982 to 1984 at Pond #4 discharge were 0.06 mg/L, 0.14 mg/L, and 0.035 mg/L, respectively. The mean ammonia, nitrate and nitrite concentrations for the same period for No Name Creek were 0.06 mg/L, 0.11 mg/L and 0.035 mg/L, respectively. Therefore, the mean inorganic nitrogen concentration for 1982 to 1984 for the Pond #4 discharge was 0.24 mg/L, while for No Name Creek it was 0.21 mg/L. The two major streams draining the pit and waste rock dump area had similar inorganic nitrogen concentrations and did not vary significantly from year to year.

In general, the inorganic nitrogen concentrations in effluents from the Line Creek Mine were low, especially in comparison with the concentrations in effluents from the Fording Coal mine (3.5 mg/L-40.1 mg/L) with the exception of Kilmarnock Creek. Concentrations in the effluents from the Westar-Greenhills mine (0.44 mg/L-0.85 mg/L) were slightly higher than the Line Creek values.

Loading data were available only for Pond #4 discharge. The mean inorganic nitrogen loading for the period 1982 to 1984 was 2.96 kg N/d. This inorganic nitrogen loading was substantially less than any of the effluent loadings at Fording (5.9 kg/d-64.5 kg/d) and slightly less than that from the Westar-Greenhills (2.9 kg/d-6.3 kg/d) mine.

In general, the maximum inorganic nitrogen loading from Pond #4 discharge occurred in May/June coincident with the maximum flows. A listing of all available data are presented in the separate Appendix report.

A summary of inorganic nitrogen and total dissolved nitrogen concentration, loading and flows for the two receiving waters (Line Creek upstream and downstream of the operations) are also presented in Table 8. A complete data set of the receiving waters is found in the separate Appendix report.

TABLE 8 SUMMARY OF CROWS NEST RESOURCES-LINE CREEK EFFLUENT AND RECEIVING WATER NITROGEN DATA

EFFLUENTS	YEAR	NH_4/NH_3 (mg/L Range (Mean)	NO_3 (mg/L) Range (Mean)	NO_2 (mg/L) Range (Mean)	TDN (mg/L) Range (Mean)	Flow (m^3/s) Range (Mean	INORGANIC N LOADING (kg/d) Range (Mean)	TDN LOADING (kg/d) Range (Mean)	NO. OF SAMPLES		
									$NH_4/$ NH_3	NO_3	NO_2
Pond #4 Discharge	1982	< 0.05-0.29 (0.146)	< 0.01-0.020 (0.11)	0.003-0.20 (0.095)		0.0051-0.1749 (0.062)	0.622-3.43 (1.76)		9	9	9
	1983	< 0.01-0.089 (0.026)	< 0.01-0.22 (0.111)	< 0.002-0.007 (0.003)		0.030-0.200 (0.105)	0.118-1.87 (0.793)		11	11	11
	1984	< 0.005-0.050 (0.015)	0.037-0.320 (0.203)	< 0.001-0.068 (0.007)		0.023-0.940 (0.160)	0.260-34.76 (6.32)		13	13	13
	1985	0.005-0.032 (0.013)	0.019-1.49 (0.386)	< 0.001-0.009 (0.004)	0.19-0.71 (0.405)	0.027-0.140 (0.065)	0.496-2.918 (1.70)		23	23	23
	1986*	0.005-0.024 (0.016)	0.191-0.549 (0.354)	< 0.001-0.044 (0.010)	0.27-0.56 (0.40)				6	6	6
No Name Creek	1982	< 0.05-0.35 (0.146)	0.012-0.20 (0.0975)	0.003-0.2 (0.101)					10	10	10
	1983	< 0.01-< 0.05 (0.020)	0.011-0.30 (0.118)	< 0.002-0.006 (0.003)					11	11	11
	1984	< 0.005-0.024 (0.012)	< 0.003-0.450 (0.123)	< 0.001-0.01 (0.002)					12	12	12
	1985	< 0.005-< 0.020 (0.008)	< 0.003-0.133 (0.058)	< 0.001-0.006 (0.004)	0.05-0.18 (0.101)	0.0594-1.231 (0.454)	0.108-4.25 (1.746)	0.0921-10.636 (4.160)	14	14	14
	1986*	0.005-0.005 (0.005)	0.09-0.112 (0.101)	0.005-0.005 (0.005)	0.12-0.12 (0.12)				2	2	2

* Data to March 1986 only

CONTINUED...

TABLE 8 (Continued)

RECEIVING WATERS	YEAR	NH_4/NH_3 (mg/L)	NO_3 (mg/L)	NO_2 (mg/L)	TDN (mg/L)	Flow (m^3/s)	INORGANIC N LOADING	TDN LOADING (kg/d)	NO. OF SAMPLES		
		Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	NH_4/NH_3	NO_3	NO_2
Line Creek Upstream	1981	0.3-0.8 (0.57)	< 0.1-0.1 (0.1)	0.1-0.3 (0.017)					3	3	3
	1982	0.05-0.35 (0.143)	0.095-0.22 (0.118)	0.002-0.1 (0.084)					12	12	12
	1983	< 0.01-< 0.05 (0.024)	< 0.01-0.19 (0.092)	< 0.002-0.018 (0.004)					11	11	11
	1984	< 0.005-0.065 (0.016)	< 0.001-0.22 (0.081)	< 0.001-< 0.01 (0.002)					12	11	12
	1985	0.005-0.025 (0.013)	< 0.003-0.21 (0.086)	< 0.001-0.008 (0.003)	0.05-0.18 (0.128)	0.280-1.529 (0.9281)	3.89-12.27 (7.165)	3.529-18.495 (10.780)	23	23	23
	1986*	0.005-< 0.020 (0.013)	0.126-0.144 (0.149)	< 0.001-0.005 (0.005)	0.13-0.16 (0.15)				6	6	6
Line Creek Downstream	1981	< 0.005-0.4 (0.068)	< 0.02-0.14 (0.078)	< 0.1-0.2 (0.133)	0.035-0.203 (0.122)	0.648-7.62 (2.97)	4.0-43.5 (21.69)	6.7-77.5 (27.63)	11	11	3
	1982	< 0.005-0.81 (0.110)	0.02-0.58 (0.076)	0.003-0.10 (0.009)	0.055-0.295 (0.161)	0.501-13.0 (2.44)	3.18-305.6 (43.74)	7.1-174.0 (35.01)	22	22	12
	1983	< 0.005-0.041 (0.015)	0.02-0.180 (0.089)	< 0.002-0.008 (0.003)	0.075-0.215 (0.145)	0.474-9.62 (2.26)	3.1-64.8 (14.82)	5.7-62.3 (25.5)	20	20	11
	1984	< 0.005-0.027 (0.010)	0.05-0.320 (0.137)	< 0.001-< 0.01 (0.002)	0.105-0.277 (0.178)	0.375-8.78 (2.01)	5.2-94.3 (18.8)	7.5-80.9 (22.82)	24	24	13
	1985	< 0.005-0.050 (0.008)	< 0.003-0.290 (0.066)	< 0.001-0.006 (0.005)	0.05-0.31 (0.121)	0.370-9.770 (2.622)	2.049-87.58 (13.77)	0.665-164.2 (24.65)	99	99	92
	1986*	0.005-< 0.020 (0.01)	< 0.001-0.89 (0.258)	< 0.001-< 0.02 (0.006)	0.18-0.23 (0.213)	0.452-0.602 (0.513)	2.1-39.27 (13.80)	8.201-11.72 (9.68)	10	10	10

* Data to March 1986 only

The mean annual inorganic nitrogen concentration for the site on Line Creek upstream of the operation from 1981 to 1984 was 0.84 mg/L, 0.35 mg/L, 0.03 mg/L, and 0.10 mg/L, respectively. The mean inorganic nitrogen concentration for the site on Line Creek downstream of the operation from 1981 to 1984 was 0.28 mg/L, 0.20 mg/L, 0.11 mg/L and 0.15 mg/L, respectively. The concentration decreased from the upstream to downstream site in 1981 and 1982 but increased in 1983 and 1984. The reason for the decrease in 1981 and 1982 is not known but the increase in 1983 and 1984 may be due to increased mining activity after 1982.

The inorganic nitrogen concentration was higher at the Line Creek upstream sample site than at upstream sites on the Fording River (Fording Coal), Michel Creek or Corbin Creek (Byron Creek Collieries). The reason for this variation is not known as there are no known sources of nitrogen to Line Creek above the mine. The inorganic nitrogen concentrations in Line Creek downstream of the mine, however, were much lower than those found in the Fording River below Fording Coal but slightly higher than those found in Corbin Creek or Michel Creek downstream of Byron Collieries. A comparison of the inorganic nitrogen loading data for the downstream site showed the same trends.

The mean inorganic nitrogen loading at the Line Creek downstream site from 1981 to 1984 was 21.7 kg/d, 43.7 kg/d, 14.8 kg/d and 18.8 kg/d, respectively. The mean inorganic nitrogen loading was substantially higher in the downstream site in 1982, but mean loadings were similar for the remaining years. Differences were due to variations in concentrations as flows were relatively constant.

To estimate the inorganic nitrogen export from the Line Creek Mine for 1983 and 1984, the loading at the upstream site was subtracted from the loading at the downstream site (Table 9). No flow data were available for the upstream site in 1983 or 1984 so the loadings at the upstream site were assumed to be 36% of the downstream loadings. This assumption was based on results from four 1985-1986 surveys conducted by EP (Section 3.4.2). The total inorganic nitrogen export from the mine area was 3 070 kg/N and 4 220 kg/N in 1983 and 1984, respectively, and represented 0.2% of the explosive used in both 1983 and 1984. This was much lower than the 1%

TABLE 9 HISTORICAL INORGANIC NITROGEN EXPORT FROM CROWS NEST RESOURCES-LINE CREEK

	1983	1984
ANNUAL INORGANIC N LOADING (kg·N)		
Line Creek upstream	1,730*	2,380*
Line Creek downstream	4,800	6,600
Net Export from Mine	3,070	4,220
EXPLOSIVE USE (kg·N) ANFO	1,527,270	2,336,403
Slurry	N.S.	N.S.
Total	1,527,270	2,336,403
ACTUAL N EXPORT AS % EXPLOSIVE	0.2%	0.2%
PREDICTED N EXPORT FROM MINE kg·N ANFO	15,273	23,364
Slurry	N.S.	N.S.
Total	15,273	23,364
PREDICTED N EXPORT AS % EXPLOSIVE	1.0%	1.0%
% ACTUAL N EXPORT OF PREDICTED	20%	18%

N.S. - not significant

* assumed to be 36% of downstream loadings based on results from four 1985-86 intensive surveys conducted by EP (Section 3.4.3)

predicted by the Pommen formula. The actual nitrogen export from the Line Creek Mine was only 20% and 18% of the predicted values for 1983 and 1984, respectively. The net export from the Line Creek mine in 1984 was slightly higher than releases from the Byron Creek Collieries and Westar-Greenhills mines but substantially lower than releases from the Fording Coal mine.

3.4.2 1985-86 Nitrogen Export. Samples were collected by Line Creek Mine, EP, and provincial Waste Management Branch (WMB) staff in 1985-86. The EP samples were collected specifically for this study. Monthly samples were collected at No Name Creek, Pond #4 discharge, and the upstream Line Creek site from April 1985 to March 1986. At the Line Creek downstream site, samples were collected weekly in April and August 1985 to March 1986. In May, June and July 1985, samples were collected daily, Monday through Friday. A few data gaps do exist (e.g. no December samples, a few daily samples are missing). The EP samples were analyzed for total inorganic nitrogen species and total dissolved nitrogen. Some flow data were collected at the time of sampling at No Name Creek, Pond #4 discharge and the upstream Line Creek site. Flow data from the WSC station (at the Line Creek downstream site) were available on all sampling days for the 1985-86 study period (Figure 10).

The WMB sampled the Line Creek downstream site on a monthly basis March through November 1985. Samples were analyzed for both total inorganic nitrogen species and total dissolved nitrogen.

Line Creek Mine staff collected samples monthly in 1985-86 from the Line Creek upstream and downstream sample sites and at the Pond #4 discharge. Occassionally samples were collected from No Name Creek. Samples were analyzed for total inorganic nitrogen species only. Some flow data were available for the Pond #4 discharge and No Name Creek.

A summary of inorganic nitrogen and total dissolved nitrogen concentrations, loadings, and flows for two effluents and two receiving waters for 1985-86 are also presented in Table 8. Inorganic nitrogen concentrations for Line Creek upstream and downstream of the mine and Pond #4 are shown in Figure 11. A complete data set is found in a separate Appendix report.

The inorganic nitrogen concentrations for the Pond #4 decant as determined by Line Creek Mine were generally higher than those concentrations

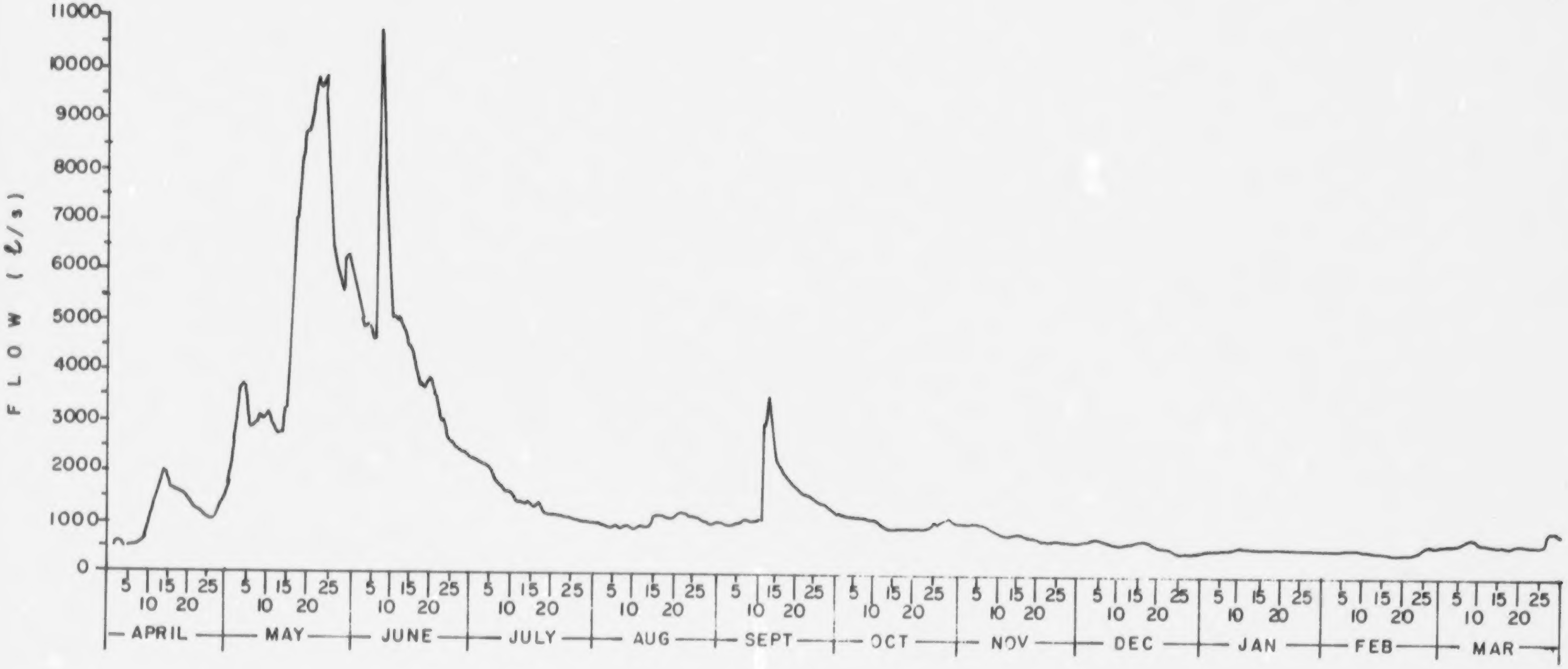
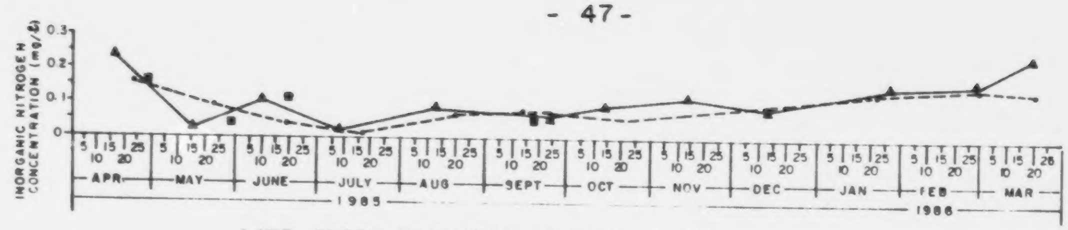
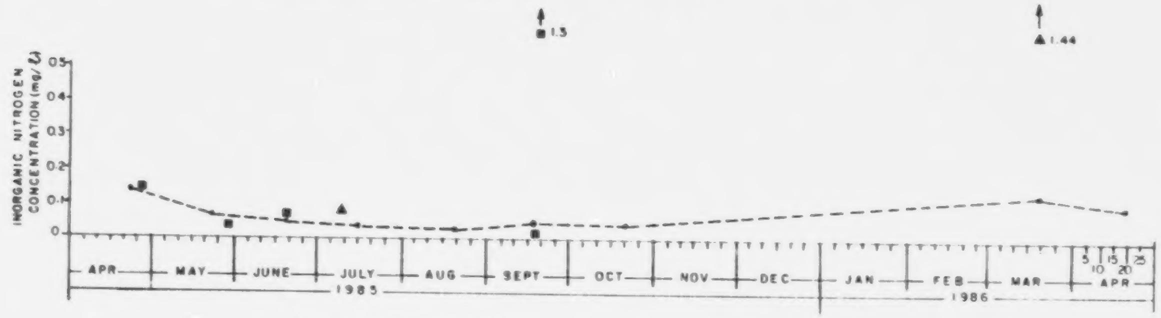


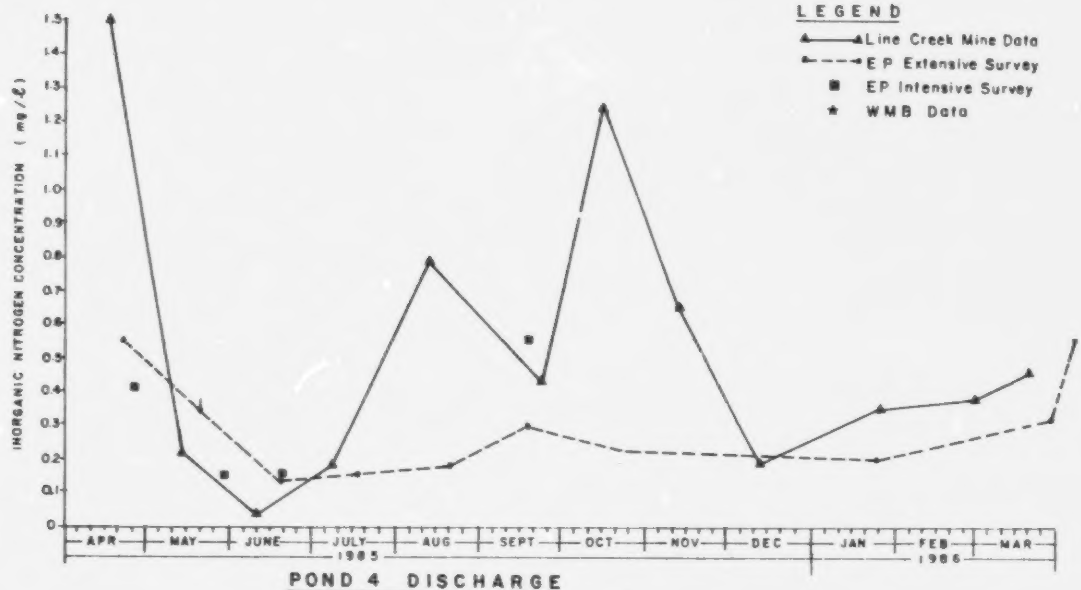
FIGURE 10 FLOW IN LINE CREEK DOWNSTREAM OF OPERATIONS - APRIL 1985 TO MARCH 1986



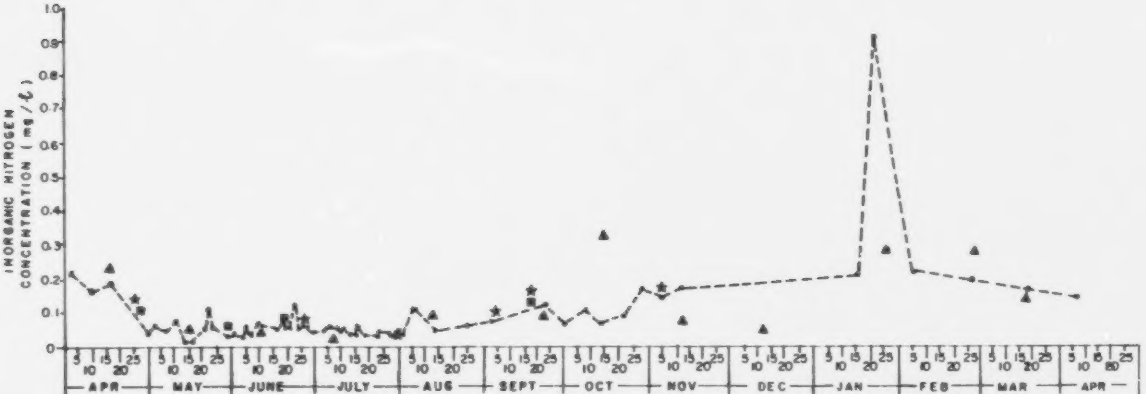
LINE CREEK UPSTREAM OF OPERATIONS



NO NAME CREEK



POND 4 DISCHARGE



LINE CREEK DOWNSTREAM OF OPERATIONS

FIGURE 11 INORGANIC NITROGEN CONCENTRATION IN DRAINAGE FROM CROWS NEST RESOURCES - LINE CREEK - APRIL 1985 TO MARCH 1986

determined by EP. All three data sources correlated well for Line Creek upstream site inorganic nitrogen concentrations. At the Line Creek downstream site, the EP extensive, EP intensive, WMB and Line Creek Mine data for inorganic nitrogen concentrations correlated extremely well for the period April 1985 to September 1985. After September 1985, generally, the Line Creek Mine samples for that site had slightly lower inorganic nitrogen concentrations than the EP samples.

The inorganic nitrogen export from Crows Nest Resources-Line Creek Mine was calculated for 1985-86 by subtracting the loading at the upstream site from the loading at the downstream site (Table 10). With the exception of flows taken at the upstream site during the four intensive surveys, no flow data were available for this site. Based on the results from these four EP surveys, the loadings at the upstream site were assumed to be approximately 36% of the downstream loadings. The total nitrogen export from the mine area in 1985-86 was 2 710 kg/N representing 0.15% of the explosive used in 1985-86. This compared to 1% predicted using the Pommen formula. The actual nitrogen export from the Line Creek mine was only 15% of the predicted value for 1985-86.

TABLE 10 1985-86 INORGANIC NITROGEN EXPORT FROM CROWS NEST RESOURCES -LINE CREEK

YEAR'S INORGANIC N LOADING (kg·N)	
Line Creek upstream	1,520*
Line Creek downstream	4,230
Net Export from Mine	2,710
EXPLOSIVE USE KG·N ANFO	1,780,000
Slurry	N.S.
Total	1,780,000
ACTUAL N EXPORT AS % EXPLOSIVE	0.15%
PREDICTED N EXPORT FROM MINE KG·N ANFO	17,800
Slurry	N.S.
Total	17,800
PREDICTED N EXPORT AS % EXPLOSIVE	1.0%
% ACTUAL N EXPORT OF PREDICTED	15%

N.S. - not significant

* assumed to be 36% of downstream loadings based on results from four 1985-86 intensive surveys conducted by EP (Section 3.4.2)

The actual 1985-86 nitrogen export of 2 710 kg/N from the mine was slightly lower than in 1983 and 1984 (3 070 kg/N and 4 220 kg/N, respectively). This decrease noted in inorganic nitrogen export from Line Creek Mine in 1985-86 as compared to previous years may be due to a more extensive data base for this period and not real differences in water quality.

3.4.3 1985-86 Sources of Nitrogen.

EP conducted four intensive surveys to determine the sources of nitrogen from the Line Creek mine in 1985-86. The surveys were conducted on April 26, May 29, June 19, and September 18, 1985. Samples were taken at 14 locations on the Line Creek minesite and analysed for inorganic nitrogen species and total dissolved nitrogen. Flows were taken where and when possible. A summary of nitrogen results for these surveys are tabulated in Table 11. The range and mean shown represent four samples at each site except Line Creek Pond #4 (3 samples), and Mine Services Diversion, Wash Bay, and South Line Creek (2 samples each).

The inorganic nitrogen loadings, or in some cases concentrations, at each of these sites are graphically presented for each survey conducted (Figures 12 to 15).

Of the 14 sample sites intensively monitored, 4 were also monitored in the extensive survey. The sites were as follows; Line Creek upstream and downstream of the operations, Pond #4 discharge and No Name Creek. The total inorganic nitrogen concentrations determined in the intensive versus the extensive survey correlated very well at the upstream and downstream sites on Line Creek and No Name Creek. The correlation was fairly good for the Pond #4 discharge results except in September when the EP intensive survey result was much higher than the EP extensive survey result. In general, there was good agreement between EP results (Figure 11).

Inorganic nitrogen concentrations at the Pond #4 discharge, as determined by mine staff, were much higher than those determined by EP (Figure 11). Concentrations determined by mine staff at Line Creek upstream and downstream correlated extremely well with those determined by EP with one exception at the Line Creek downstream site in January 1986. The

TABLE 11 SUMMARY OF CROWS NEST RESOURCES-LINE CREEK 1985 EP INTENSIVE SURVEY NITROGEN RESULTS

LOCATION	FLOW (L/s) Range (Mean)	TDN (mg/L) Range (Mean)	NO_3 (mg/L) Range (Mean)	NH_3 (mg/L) Range (Mean)	NO_2 (mg/L Range (Mean)	LOADING TDN (kg/d) Range (Mean)	LOADING INORG. N (kg/d) Range (Mean)
Line Creek U/S	280-1529(928)	0.12-0.15(0.14)	0.03-0.151(0.098)	<0.005-0.006(0.006)	<0.005-0.008(0.006)	3.6-18.5(10.7)	3.9-12.3(7.2)
No Name Ck	71-1231(454)	0.08-0.18(0.128)	0.03-0.132(0.055)	<0.005-0.006(0.005)	<0.005(0.005)	0.9-10.6(4.2)	0.11-4.2(1.8)
Inflow Pond #1	14-23(17)	1.5-3.1(2.3)	0.765-2.95(1.76)	<0.005-0.083(0.025)	<0.005-0.48(0.124)	3.2-4.2(3.3)	0.95-3.8(2.8)
Line Ck @ Pond #5 & #6	-	0.08-0.17(0.13)	0.033-0.15(0.073)	<0.005-0.007(0.006)	<0.005-0.055(0.0175)	-	-
West Line Creek	-	0.17-0.46(0.31)	0.129-0.39(0.248)	<0.005-0.006(0.005)	<0.005(<0.005)	-	-
Pond #4	-	0.19-0.63(0.388)	0.14-0.54(0.307)	<0.005-0.008(0.006)	<0.005(<0.005)	-	-
BEP Ditch	4-8(7)	0.48-1.3(0.935)	0.35-0.985(0.681)	<0.005-0.006(0.005)	<0.005(<0.005)	0.18-0.68(0.51)	0.13-0.65(0.39)
Line Ck D/S Pond #4	-	0.15-0.20(0.17)	0.11-0.192(0.157)	<0.005(0.005)	<0.005(<0.005)	-	-
Line Ck D/S	1010-5530(2990)	0.08-0.147(0.114)	0.05-0.12(0.082)	<0.005(0.005)	<0.005(<0.005)	11-38(26)	9.6-29(20)
Mine Services Division	0.38-0.81(0.60)	0.14-0.15(0.14)	0.019-0.023(0.021)	<0.005-0.006(0.006)	<0.005(<0.005)	0.005-0.01(0.007)	0.001-0.002(0.002)
Wash Bay	0.26(0.26)	1.3-1.6(1.4)	<0.005-0.019(0.012)	0.024-0.059(0.042)	0.022-0.24(0.023)	0.03(0.03)	0.002(0.002)
South Line Ck	-	0.08-0.11(0.095)	0.039-0.061(0.05)	<0.005(<0.005)	<0.005(<0.005)	-	-

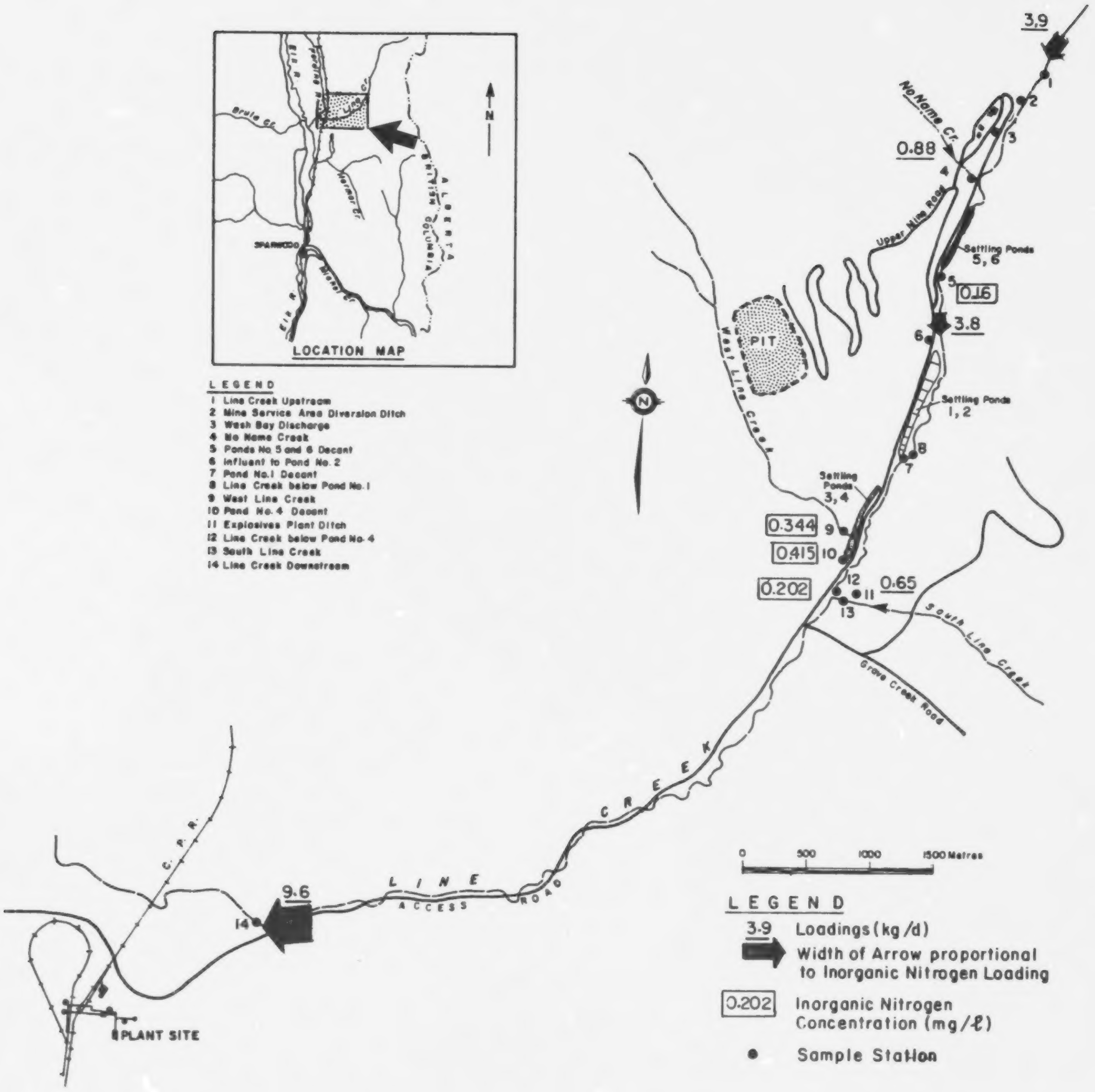

LOCATION MAP
Elk R.
Fording R.
Line Cr.
Brule Cr.
Michel Cr.
Harmer Cr.
SPARWOOD
ALBERTA
BRITISH COLUMBIA
N
LEGEND
1 Line Creek Upstream
2 Mine Service Area Diversion Ditch
3 Wash Bay Discharge
4 No Name Creek
5 Ponds No. 5 and 6 Decant
6 Influent to Pond No. 2
7 Pond No. 1 Decant
8 Line Creek below Pond No. 1
9 West Line Creek
10 Pond No. 4 Decant
11 Explosives Plant Ditch
12 Line Creek below Pond No. 4
13 South Line Creek
14 Line Creek Downstream
3.9
No Name Cr.
0.88
Upper Mine Road
Settling Ponds 5, 6
0.16
3.8
PIT
West Line Creek
Settling Ponds 1, 2
Settling Ponds 3, 4
0.344
0.415
0.202
0.65
South Line Creek
Greave Creek Road
LINE CREEK
ACCESS ROAD
9.6
C.P.R.
PLANT SITE
0 500 1000 1500 Metres
LEGEND
3.9 Loadings (kg/d)
Width of Arrow proportional to Inorganic Nitrogen Loading
0.202 Inorganic Nitrogen Concentration (mg/ℓ)
● Sample Station

FIGURE 12 INORGANIC NITROGEN LOADINGS AND CONCENTRATIONS FOR EP INTENSIVE SURVEY - APRIL 26, 1986

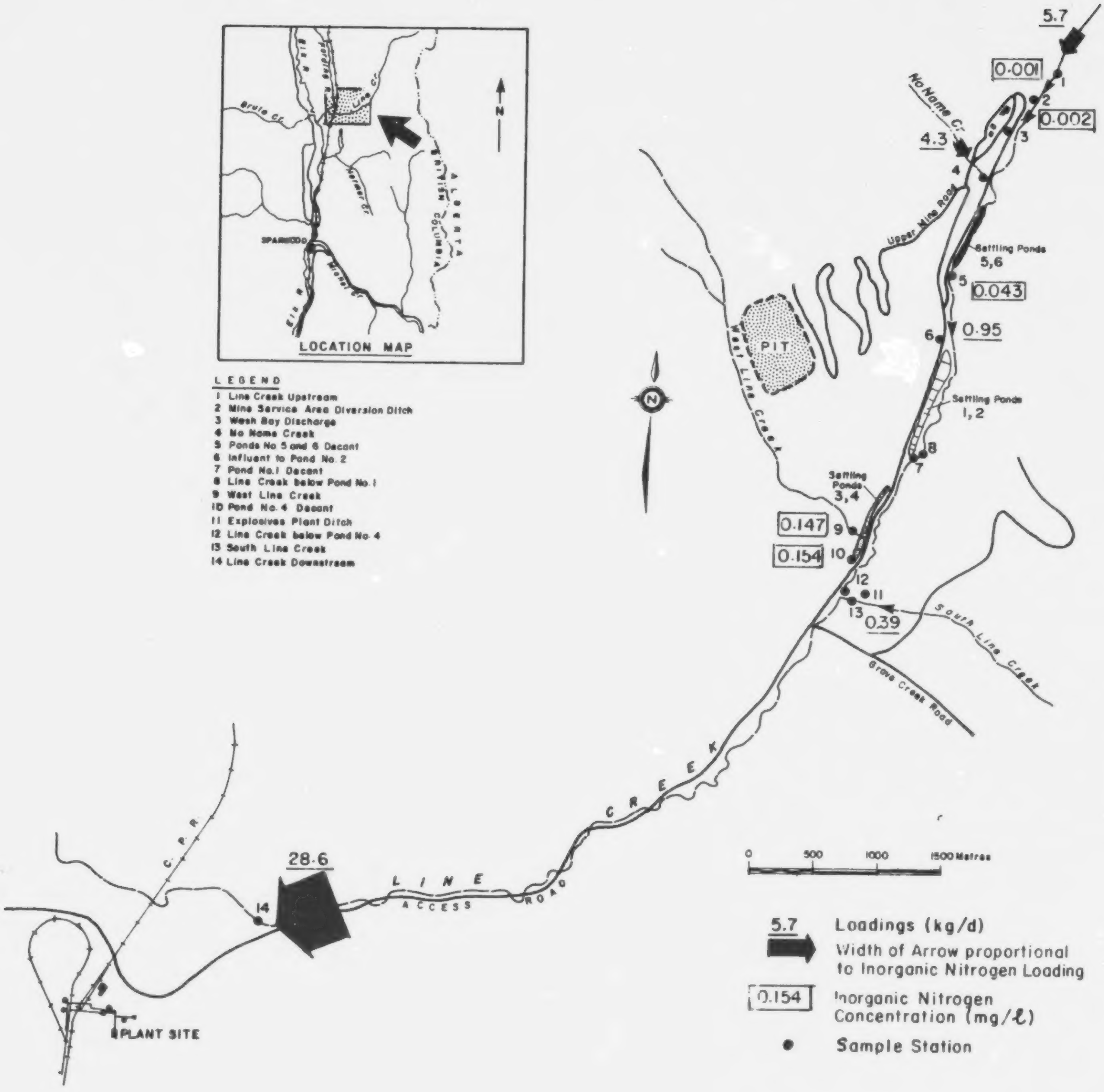

LOCATION MAP
Elk R.
Fording R.
Line Cr.
Brule Cr.
Harmer Cr.
SPARWOOD
Michel Cr.
ALBERTA
BRITISH COLUMBIA
N
LEGEND
1 Line Creek Upstream
2 Mine Service Area Diversion Ditch
3 Wash Bay Discharge
4 No Name Creek
5 Ponds No 5 and 6 Decant
6 Influent to Pond No. 2
7 Pond No.1 Decant
8 Line Creek below Pond No. 1
9 West Line Creek
10 Pond No. 4 Decant
11 Explosives Plant Ditch
12 Line Creek below Pond No. 4
13 South Line Creek
14 Line Creek Downstream
5.7
0.001
0.002
No Name Cr.
4.3
Upper Mine Road
Settling Ponds 5,6
0.043
0.95
PIT
West Line Creek
Settling Ponds 1,2
Settling Ponds 3,4
0.147
0.154
0.39
South Line Creek
Grave Creek Road
LINE CREEK
ACCESS ROAD
28.6
C.P.R.
PLANT SITE
0 500 1000 1500 Metres
5.7 Loadings (kg/d)
Width of Arrow proportional to Inorganic Nitrogen Loading
0.154 Inorganic Nitrogen Concentration (mg/ℓ)
● Sample Station

FIGURE 13 INORGANIC NITROGEN LOADINGS AND CONCENTRATIONS FOR EP INTENSIVE SURVEY - MAY 29, 1985

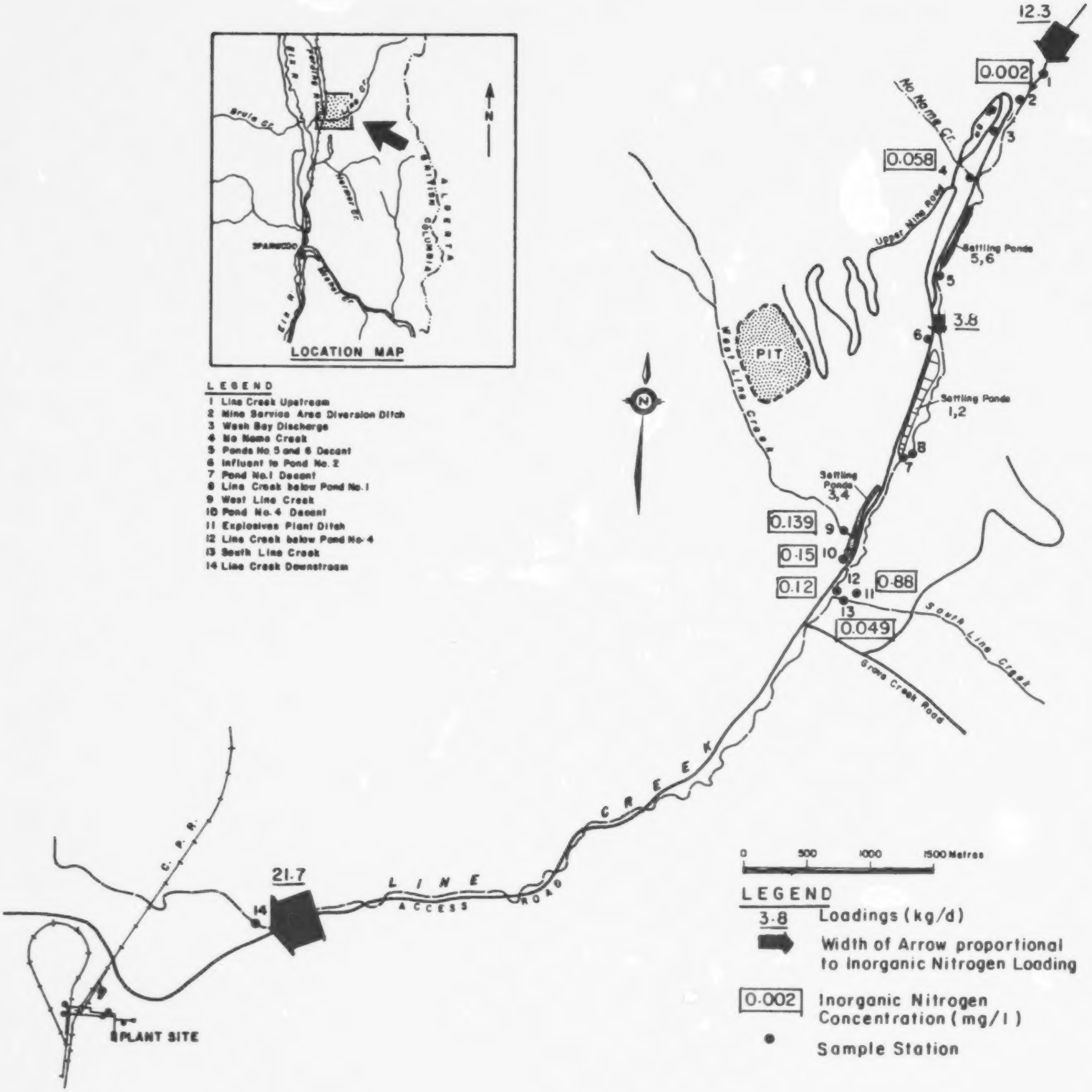

Elk R.
Fording R.
Line Cr.
Brule Cr.
Harmer Cr.
SPARWOOD
Michel Cr.
Elk R.
ALBERTA
BRITISH COLUMBIA
N
LOCATION MAP
LEGEND
1 Line Creek Upstream
2 Mine Service Area Diversion Ditch
3 Wash Bay Discharge
4 No Name Creek
5 Ponds No. 5 and 6 Decant
6 Influent to Pond No. 2
7 Pond No. 1 Decant
8 Line Creek below Pond No. 1
9 West Line Creek
10 Pond No. 4 Decant
11 Explosives Plant Ditch
12 Line Creek below Pond No. 4
13 South Line Creek
14 Line Creek Downstream
12.3
0.002
1
2
3
No Name Cr.
0.058
4
Upper Mine Road
Settling Ponds 5,6
5
6
3.8
PIT
West Line Creek
Settling Ponds 1,2
8
7
N
Settling Ponds 3,4
0.139
9
0.15
10
12
0.12
11
0.88
13
0.049
South Line Creek
Grave Creek Road
LINE CREEK
ACCESS ROAD
C.P.R.
21.7
14
PLANT SITE
0
500
1000
1500 Metres
LEGEND
3.8 Loadings (kg/d)
Width of Arrow proportional to Inorganic Nitrogen Loading
0.002 Inorganic Nitrogen Concentration (mg/l)
Sample Station

FIGURE 14 INORGANIC NITROGEN LOADINGS AND CONCENTRATIONS FOR EP INTENSIVE SURVEY - JUNE 19, 1985

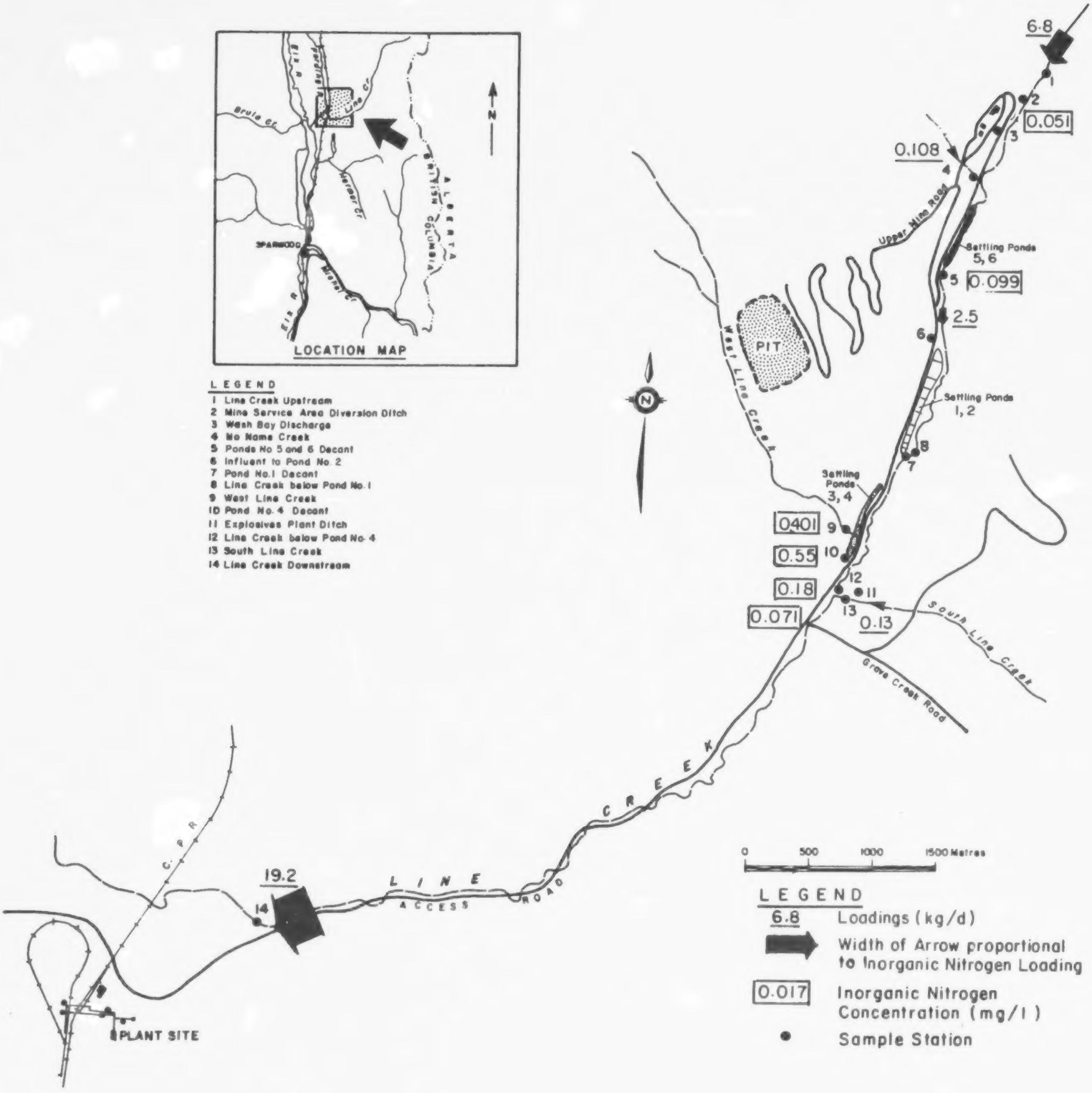

LOCATION MAP
N
Brule Cr.
Elk R.
Fording R.
Line Cr.
Harmer Cr.
Michel Cr.
SPARWOOD
ALBERTA
BRITISH COLUMBIA
LEGEND
1 Line Creek Upstream
2 Mine Service Area Diversion Ditch
3 Wash Bay Discharge
4 No Name Creek
5 Ponds No 5 and 6 Decant
6 Influent to Pond No. 2
7 Pond No.1 Decant
8 Line Creek below Pond No. 1
9 West Line Creek
10 Pond No. 4 Decant
11 Explosives Plant Ditch
12 Line Creek below Pond No. 4
13 South Line Creek
14 Line Creek Downstream
N
6.8
1
2
0.051
3
0.108
4
Upper Mine Road
Settling Ponds 5, 6
5
0.099
2.5
6
PIT
West Line Creek
Settling Ponds 1, 2
8
7
Settling Ponds 3, 4
0.401
9
0.55
10
12
0.18
11
13
0.071
0.13
South Line Creek
Grave Creek Road
LINE CREEK
ACCESS ROAD
19.2
14
C.P.R.
PLANT SITE
0 500 1000 1500 Metres
LEGEND
6.8 Loadings (kg/d)
Width of Arrow proportional to Inorganic Nitrogen Loading
0.017 Inorganic Nitrogen Concentration (mg/l)
● Sample Station

FIGURE 15 INORGANIC NITROGEN LOADINGS AND CONCENTRATIONS FOR EP INTENSIVE SURVEY - SEPTEMBER 18, 1985

concentrations as determined by WMB at the Line Creek downstream site correlated very well with the concentrations determined by both mine staff and EP.

The point source effluents examined in the intensive surveys were as follows; No Name Creek, Inflow to Pond #1, West Line Creek, Pond #4 decant, BEP Ditch, Mine Services area diversion ditch, the Wash Bay discharge and South Line Creek. The highest mean inorganic nitrogen concentrations were found in the Inflow to Pond #1 (1.91 mg/L) and the BEP Ditch (0.7 mg/L) while the lowest concentrations were found in the Mines Services area diversion ditch (0.3 mg/L) (Table 11).

At most of the effluent sites, flow data did not exist. Therefore, loadings from these sites could not be determined and compared. The greatest loadings to the Line Creek system were suspected to be from No Name Creek, Inflow to Pond #1 and Pond #4 Discharge. Although the inorganic nitrogen concentration in the Pond #4 Discharge was moderate when compared to other sources, the flow from a basin of this size would cause the loadings to be greater.

Several sites were examined along Line Creek. These are; Line Creek above the operations, Line Creek at Pond #5 and #6 decant, Line Creek below Pond #4 decant, and Line Creek downstream of the operations. The mean inorganic nitrogen concentration varied along the length of Line Creek. From Line Creek above the operation to Line Creek at Pond #5 and #6 decant, the mean inorganic nitrogen concentration decreased; between Line Creek at Pond #5 and #6 decant and Line Creek below Pond #4 decant, the concentration increased; and between Line Creek below Pond #4 decant and the downstream sample site on Line Creek, the concentration decreased again. Generally, this trend was due to inputs and dilution effects. For example, the increases between Ponds #5 and #6 and Line Creek below Pond #4 discharge were probably the result of inputs to the system from several point sources (eg. Influent to Pond #1, Pond #4 discharge). The decrease between Line Creek below Pond #4 and the downstream site was probably due to dilution as no large point source effluents discharged into the system between these sites (eg. the loading from the explosives plant ditch and the concentration from South Line Creek were both low and, therefore, were not considered significant).

In general, the loading in Line Creek increased from the upstream to the downstream site throughout the four intensive surveys. The May 28 survey indicated a five-fold change in inorganic nitrogen loading from the upstream to downstream site. This corresponded to peak flows in Line Creek and reflected nitrogen inputs from the mine.

3.4.4 **1985-86 Phosphorus Export.** Phosphorus data were available for Line Creek downstream of the mine from 1981 to 1986 and for other sites for 1985 and 1986 only. The range and mean of total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP) and total phosphorus (TP) for the entire data base are shown in Table 12. TDP, SRP and TP concentrations may have been slightly lower in 1985 and 1986 than for previous years but the difference is small and possibly influenced by the variation in data base sizes between each year.

TDP concentrations for Line Creek upstream and downstream of operations and Pond 4 discharge are shown in Figure 16. In general, results were at or close to the detection limit (0.002 mg/L) with the exception of the freshet period (May to July). Data from the two EP surveys were in reasonable agreement, but results for Line Creek downstream of operations obtained by the WMB tended to be higher. The plots do not show any obvious increase in TDP in the Pond #4 discharge or Line Creek downstream of operations compared to Line Creek upstream.

The EP extensive survey results for 1985-86 indicated that TDP and SRP were roughly equivalent at the two Line Creek sites and in Pond #4. The mean TDP concentration for No Name Creek was skewed by one value of 0.14 mg/l. The accuracy of this measurement is suspect. Excluding this one value from the EP results, the 1985-86 mean TDP concentration of 0.003 mg/L (based on 8 values) was comparable to means for the other three sites. Detailed results are included in a separate Appendix report.

These mean annual concentrations, however, were biased by the more extensive data gathered during May, June and July. To overcome this bias, the mean phosphorus species' concentrations were calculated for each quarter (Table 13). With the exception of TP for No Name Creek, there was a tendency towards higher phosphorus concentrations in April-June and January-March

TABLE 12 SUMMARY OF CROWS NEST RESOURCES-LINE CREEK EFFLUENT AND RECEIVING WATER PHOSPHORUS DATA

EFFLUENTS	YEAR	TDP (mg/L)	SRP (mg/L)	TP (mg/L)	TDP LOADING (kg/d)	SRP LOADING (kg/d)	TP LOADING (kg/d)	NO. OF SAMPLES		
		Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	TDP	SRP	TP
Pond #4 Discharge	1982							0	0	0
	1983							0	0	0
	1984							0	0	0
	1985	<0.002-0.012 (0.003)	<0.002-<0.002 (<0.002)	<0.002-0.029 (0.007)				11	7	11
	1986*	<0.002-0.005 (0.003)	0.004-0.006 (0.005)	0.006-0.18 (0.066)				3	3	3
No Name Creek	1982							0	0	0
	1983							0	0	0
	1984							0	0	0
	1985	<0.002-0.021 (0.006)	<0.002-<0.002 (<0.002)	<0.002-0.55 (0.097)	0.018-2.2335 (0.787)		0.25-2.823 (1.911)	10	7	11
	1986*	<0.002-<0.002 (<0.002)	0.004-0.004 (0.004)	0.026-0.026 (0.026)				2	2	2

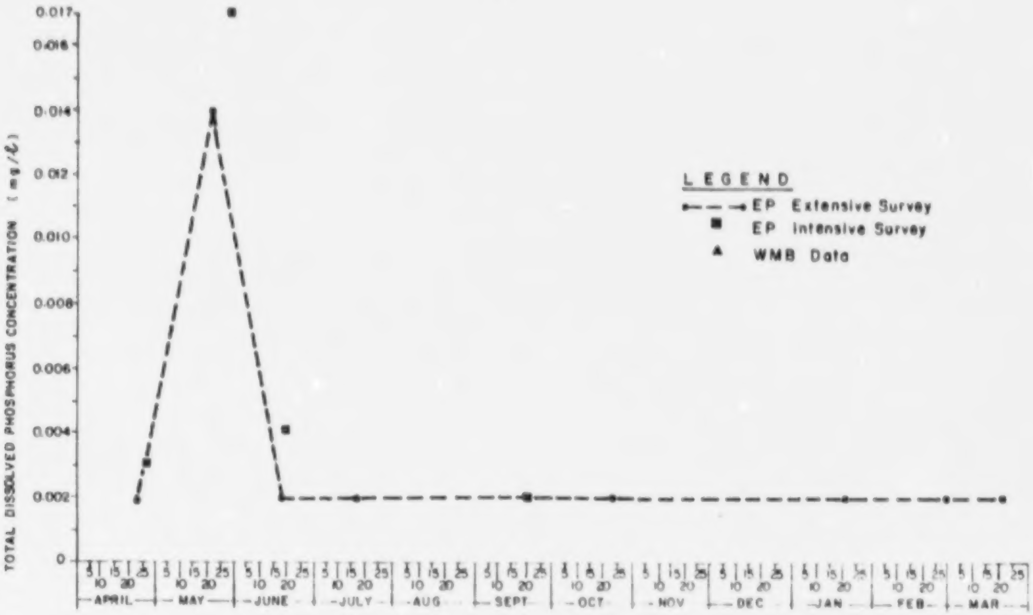
* Data to March 1986 only

CONTINUED...

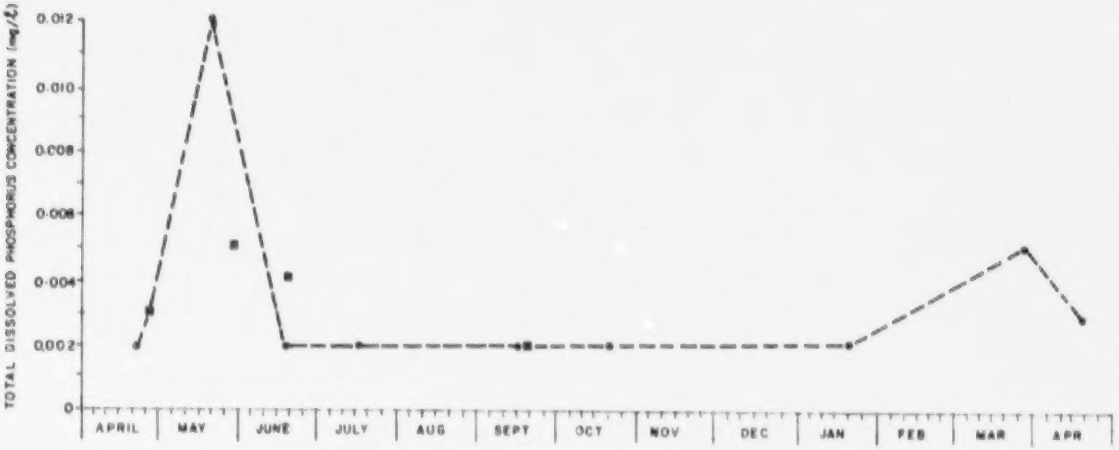
TABLE 12 (Continued)

RECEIVING WATERS	YEAR	TDP (mg/L) Range (Mean)	SRP (mg/L) Range (Mean)	TP (mg/L) Range (Mean)	TDP LOADING (kg/d) Range (Mean)	SRP LOADING (kg/d) Range (Mean)	TP LOADING (kg/d) Range (Mean)	NO. OF SAMPLES TDP	NO. OF SAMPLES SRP	NO. OF SAMPLES TP
Line Creek Upstream	1981							0	0	0
	1982							0	0	0
	1983							0	0	0
	1984							0	0	0
	1985	<0.002-0.017 (0.005)	<0.002-0.004 (0.002)	<0.002-0.059 (0.010)	0.073-2.2458 (0.716)		0.073-2.2458 (0.739)	11	7	11
	1986*	<0.002-<0.002 (<0.002)	0.004-0.005 (0.005)	0.003-0.009 (0.005)				3	3	3
Line Creek Downstream	1981	0.004-0.12 (0.008)	0.003-0.008 (0.005)	0.006-0.055 (0.025)	0.29-6.96 (2.52)	0.18-4.64 (1.65)	0.35-19.13 (7.57)	7	7	7
	1982	0.005-0.008 (0.006)	<0.003-0.006 (0.004)	0.007-0.026 (0.011)	0.22-7.86 (1.50)	0.12-6.74 (1.13)	0.30-29.20 (4.28)	10	10	10
	1983	0.004-0.010 (0.007)	<0.003-0.005 (0.004)	0.005-0.013 (0.009)	0.21-3.91 (1.16)	0.12-1.95 (0.643)	0.21-4.69 (1.66)	7	7	7
	1984	0.005-0.011 (0.007)	<0.003-0.005 (0.003)	0.005-0.014 (0.009)	0.20-5.08 (1.29)	0.12-1.85 (0.568)	0.24-6.47 (1.745)	8	8	8
	1985	<0.002-0.013 (0.003)	<0.002-0.003 (0.002)	<0.002-0.018 (0.007)	0.012-4.3001 (0.638)	0.012-1.688 (0.462)	0.012-13.61 (1.14)	86	83	86
	1986*	<0.002-0.014 (0.004)	0.004-0.006 (0.005)	0.004-0.014 (0.009)	0.078-0.153 (0.112)	0.156-0.259 (0.213)	0.156-0.532 (0.316)	7	7	7

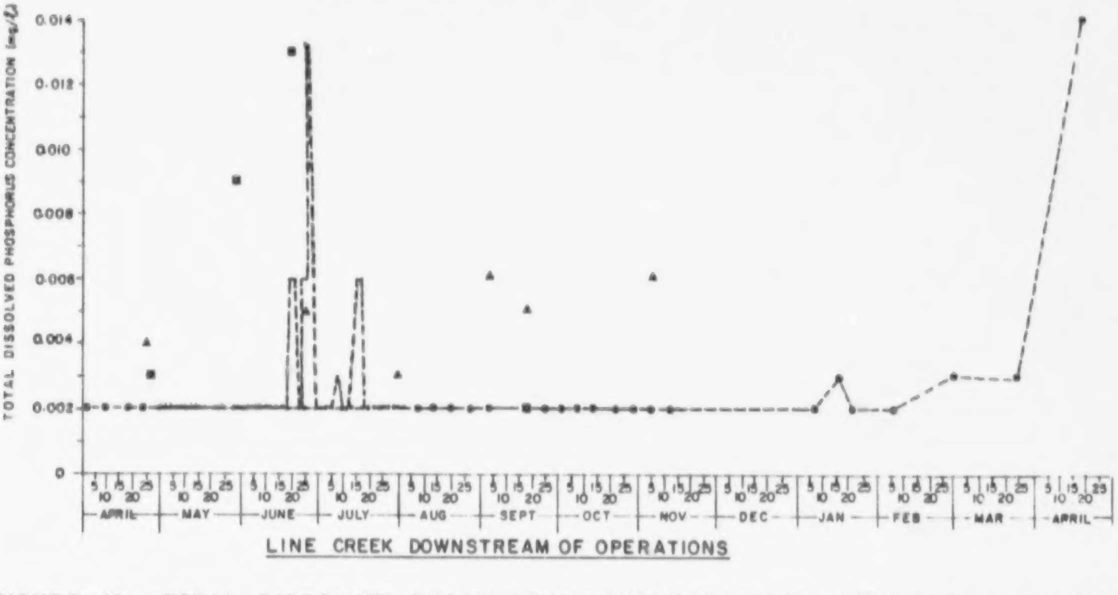
* Data to March 1986



LINE CREEK UPSTREAM OF OPERATIONS



POND 4 DISCHARGE



LINE CREEK DOWNSTREAM OF OPERATIONS

FIGURE 16 TOTAL DISSOLVED PHOSPHORUS CONCENTRATIONS - LINE CREEK DRAINAGES APRIL 1985 TO MARCH 1986

TABLE 13 MEAN TDP, SRP, TP CONCENTRATIONS BY QUARTER 1985-86 EP DATA*
CROWS NEST RESOURCES-LINE CREEK

LOCATION	MEAN CONCENTRATION (mg/L)				MEAN FOR YEAR
	APR - JUN	JUL - SEP	OCT - DEC	JAN - MAR	
TDP					
Line Ck u/s	0.006	0.002	0.002	0.002	0.003
Line Ck d/s	0.003	0.002	0.002	0.004	0.003
Pond #4	0.005	0.002	0.002	0.003	0.003
No Name Ck	0.004	0.002	0.002	0.002	0.002
SRP					
Line Ck u/s	0.003	0.002	0.002	0.005	0.003
Line Ck d/s	0.002	0.002	0.002	0.005	0.003
Pond #4	0.002	0.002	0.002	0.005	0.003
No Name Ck	0.002	0.002	0.002	0.004	0.002
TP					
Line Ck u/s	0.023	0.002	0.002	0.005	0.008
Line Ck d/s	0.007	0.007	0.002	0.008	0.006
Pond #4	0.013	0.002	0.002	0.066	0.021
No Name Ck	0.009	0.138	0.002	0.026	0.044

* EP extensive survey data only

compared to July - December. These elevated concentrations appeared at times of higher flows. The mean TP concentration for No Name Creek in the July-September period was skewed by one high value out of three. The other two values were at or just above detection.

In general, there was little difference between the TDP and SRP concentrations in Line Creek upstream and downstream of the mine; the means of the four quarters were identical. The two effluent streams contained about the same TDP and SRP concentrations as the Line Creek stations. The TP results were more variable with possible increases in the downstream site in July-September and January-March compared to upstream Line Creek. The effluent TP concentrations were lower than the upstream Line Creek site for all quarters except January - March.

Concentrations above the detection limit may have skewed the mean concentrations shown in Table 13. As a further aid to assess the potential of the mine as a phosphorus source, the percent values greater than the phosphorus detection limit (0.002 mg/L) were calculated for each quarter (Table 14). These data also indicated a tendency to higher phosphorus readings in April - June and January - March compared to July - December. In general, there were more detectable TDP values downstream of the mine in Line Creek compared to upstream in July - September and January - March and less in April - June reflecting increased flows and associated dilution during freshet. Percentages in effluents were variable throughout the year. Overall, there may have been a slightly greater tendency for detectable TDP downstream in the effluents compared to upstream. SRP percentages showed little overall differences. For TP, the downstream site had more values above detection limit than the upstream site from April to June but fewer, or just as many, during the rest of the year. Effluent results were again variable but differences were slight compared to the upstream Line Creek site.

TABLE 14 **MEAN TDP, SRP, TP CONCENTRATIONS GREATER THAN DETECTION LIMIT 1985-86 EP DATA* CROWS NEST RESOURCES-LINE CREEK**

LOCATION	% VALUES GREATER THAN DETECTION LIMIT				MEAN FOR YEAR
	APR - JUN	JUL - SEP	OCT - DEC	JAN - MAR	
TDP					
Line Ck u/s	33	0	0	0	8
Line Ck d/s	18	11	0	57	22
Pond #4	33	0	0	66	25
No Name Ck	33	33	0	0	16
SRP					
Line Ck u/s	33	0	0	100	33
Line Ck d/s	2	0	0	100	26
Pond #4	0	0	0	100	25
No Name Ck	0	0	0	100	25
TP					
Line Ck u/s	67	33	0	100	50
Line Ck d/s	98	26	0	100	56
Pond #4	67	0	0	100	42
No Name Ck	67	67	0	100	58

* EP extensive survey data only

Results from the four intensive EP surveys were also examined to determine any differences in phosphorus levels around the mine (Table 15). On two occasions (May 29 and June 19), the upstream Line Creek TDP concentration differed significantly from the downstream site. On May 29, the upstream TDP concentration was higher than the downstream (0.017 mg/L and 0.009 mg/l, respectively) but on June 19 the upstream was lower (0.004 mg/L and 0.013 mg/L, respectively). However, the mean TDP concentrations for the four surveys were identical for the upstream and downstream sites. TDP loading at the downstream site was greater than at the upstream site on all days but this was largely due to higher flows at the downstream site.

Some effluents contained elevated concentrations of TDP during the intensive surveys. The Wash Bay, Mine Services diversion ditch, Pond #1 and No Name Creek contained higher TDP concentrations than receiving waters. With the exception of No Name Creek, these all contributed small flows and phosphorus loadings to the creek. No Name Creek contained a mean TDP concentration of 0.013 mg/L (range 0.003-0.021 mg/L). The mean loading was close to the upstream Line Creek value and about 34% of the downstream.

SRP results from the intensive surveys indicated most effluents contained higher concentrations than receiving waters. No Name Creek, Inflow to Pond #1, West Line Creek, Pond #4 decant, Mine Service area diversion ditch, Wash Bay discharge, and South Line Creek all had slightly higher mean SRP concentrations than receiving waters. The Inflow into Pond #1 and the Wash Bay discharge, in particular, contained high SRP concentrations (mean 0.033 mg/L and 0.155 mg/L, respectively). Line Creek downstream of the mine contained slightly higher SRP than the upstream site (0.004 mg/L compared to 0.003 mg/L).

Most of the effluents contained higher concentrations of TP during the intensive surveys than the receiving waters; examples included Inflow to Pond #1, BEP ditch, Mine Service area ditch, Wash Bay discharge, South Line Creek, and Pond #4 decant. The Inflow to Pond #1 and the Wash Bay discharge (mean 0.616 mg/L and 1.32 mg/L, respectively), in particular, appeared to have consistently higher concentrations of TP compared to receiving waters. The mean TP concentration downstream of the mine was slightly higher than the upstream (0.010 mg/L versus to 0.007 mg/L) although relative differences

TABLE 15 SUMMARY OF CROWS NEST RESOURCES - LINE CREEK 1985 EP INTENSIVE SURVEY PHOSPHORUS RESULTS

LOCATION	TDP (mg/L) Range (Mean)	TP (mg/L) Range (Mean)	SRP (mg/L) Range (Mean)	LOADING TDP (kg/d) Range (Mean)
Line Creek* u/s	0.002-0.017(0.007)	0.003-0.017(0.007)	0.002-0.0036(0.003)	0.116-2.2(0.72)
No Name Creek	0.003-0.021(0.013)	0.005-0.55(0.155)	0.002-0.016(0.008)	0.018-2.2(0.79)
Inflow Pond #1	0.012-0.041(0.025)	0.061-1.3(0.61)	0.024-0.046(0.033)	0.015-0.038(0.035)
Line Creek @ Pond #5 & #6*	0.002-0.005(0.003)	0.002-0.005(0.004)	0.002-0.004(0.002)	-
West Line Creek	0.002-0.019(0.007)	0.003-0.01(0.006)	0.002-0.007(0.004)	-
Pond #4 Decant	0.002-0.005(0.004)	0.004-0.011(0.006)	0.002-0.008(0.004)	-
BEP Ditch	0.002-0.006(0.003)	0.002-1.1(0.278)	0.002-0.002(0.002)	0.001-0.002(0.002)
Line Creek d/s Pond #4*	0.002-0.004(0.003)	0.002-0.003(0.002)	0.002-0.003(0.002)	-
Line Creek* d/s	0.003-0.013(0.007)	0.003-0.013(0.010)	0.002-0.007(0.004)	0.26-4.3(2.3)
Mine Services Diversion	0.015-0.027(0.021)	0.015-5.1(2.56)	0.011-0.028(0.020)	0.0009-0.001(0.001)
Wash Bay	0.48(0.48)	1.23-1.41(1.32)	0.267-0.042(0.155)	0.011(0.011)
South Line Creek	0.002-0.008(0.005)	0.013-0.02(0.017)	0.002-0.018(0.01)	-

*receiving water sites

between results on the same sampling dates were variable.

Each of the three data sets examined in this section had strengths and weaknesses. All the data combined produced the largest work base but annual means were skewed by the larger number of results during the freshet. Variations in the size of data sets for each station also made comparisons difficult. The calculation of quarterly means for the EP extensive survey maintained a relatively large data base and reduced the influence of different sample sizes for the various quarters. As with the "all data" set, the EP extensive data analysis suffered from differences in data sizes for the various sampling locations. The EP intensive survey results had equal data sizes for each location but each set was made up of only four samples. Samples collected during the EP intensive survey were preserved according to standard procedures for phosphorus while samples collected at other times were not. The effect of different presentation techniques is not known. However, results of TDP analyses for the four EP intensive surveys agree reasonably well with trends identified by the EP extensive survey samples (Figure 16).

A comparison of the mean phosphorus species concentrations for the three data sets is shown in Table 16. The change in mean phosphorus concentration in Line Creek downstream, Pond #4 decant, and No Name Creek compared to Line Creek upstream are also presented. The mean change in concentration for the three data sets was calculated for the one receiving water and two major effluent discharges. In general, the Pond #4 discharge did not appear to contribute any TDP or SRP to Line Creek compared to the upstream receiving water site. The TP concentration at the Pond #4 discharge was, on average, 0.003 mg/L above the concentration at the upstream site but results were variable between data sets. The No Name Creek discharge may have contributed an average of 0.002 mg/L TDP, 0.001 mg/L SRP, and 0.090 mg/L TP above background. Of the three phosphorus species, TP was the major contribution from the effluents.

The downstream Line Creek site contained lower average concentrations of TDP and TP than the upstream site. If effluents were a source of phosphorus to Line Creek, their contributions must have been small and the impacts localized.

TABLE 16 SUMMARY OF MEAN PHOSPHORUS SPECIES CONCENTRATIONS ACCORDING TO VARIOUS DATA SETS - CROWS NEST RESOURCES-LINE CREEK

LOCATION	1985 ALL DATA		1985-86 EP EXTENSIVE		1985-86 EP INTENSIVE		MEAN CHANGE FROM u/s (mg/L)
	Mean (mg/L)	Change From u/s (mg/L)	Mean (mg/L)	Change From u/s (mg/L)	Mean (mg/L)	Change From u/s (mg/L)	
TDP							
Line Ck u/s	0.005		0.003		0.007		
Line Ck d/s	0.003	- 0.002	0.003	0	0.007	0	- 0.002
Pond #4	0.003	- 0.002	0.003	0	0.004	- 0.003	- 0.002
No Name Ck	0.006	+ 0.001	0.002	- 0.001	0.013	+ 0.006	+ 0.002
SRP							
Line Ck u/s	0.002		0.003		0.003		
Line Ck d/s	0.002	0	0.003	0	0.004	+ 0.001	0
Pond #4	0.002	0	0.003	0	0.004	+ 0.001	0
No Name Ck	0.002	0	0.002	- 0.001	0.008	+ 0.004	+ 0.001
TP							
Line Ck u/s	0.010		0.008		0.007		
Line Ck d/s	0.007	- 0.003	0.006	- 0.002	0.010	+ 0.003	- 0.001
Pond #4	0.007	- 0.003	0.021	+ 0.013	0.006	- 0.001	+ 0.003
No Name Ck	0.097	+ 0.087	0.044	+ 0.036	0.155	+ 0.148	+ 0.090

3.5 Westar Mining - Balmer Operation

Westar Mining Ltd. operates two major mining facilities in the southeast. The Balmer mine has been in operation since 1969 and is located near Sparwood (Figure 17). The Greenhills Operation is the company's newly constructed surface mine 35 km north of the existing Balmer Operation near the town of Elkford (see discussion Section 3.2).

Westar Mining Ltd.'s Balmer Operation straddles a rich coal belt known as Harmer Ridge that contains proven recoverable reserves of more than 225 million tonnes of clean coal. The mine is drained by four major streams: the Elk River on the west; Michel Creek on the southwest; Harmer Creek on the north which flows north through a U-shaped valley between the steep slopes of

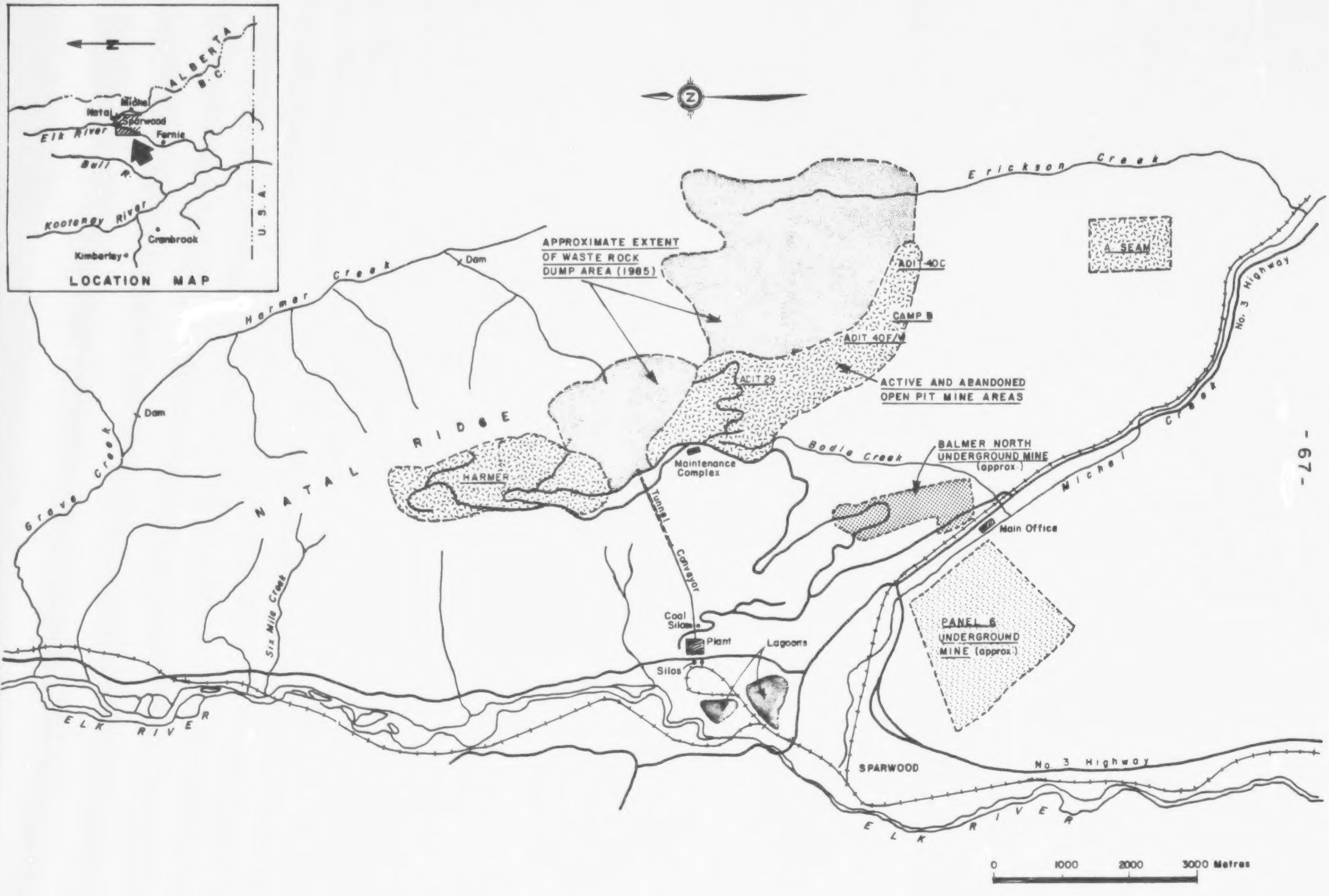

LOCATION MAP
N
ALBERTA
B.C.
Michel
Natal
Sparwood
Fernie
Elk River
Bull R.
Kootenay River
Cranbrook
Kimberley
U.S.A.
N
APPROXIMATE EXTENT OF WASTE ROCK DUMP AREA (1985)
ACTIVE AND ABANDONED OPEN PIT MINE AREAS
Erickson Creek
A SEAM
ADIT 40C
CAMP B
ADIT 40F/W
ADIT 29
Harmer Creek
Dam
Dam
Grave Creek
NATAL RIDGE
HARMER
Maintenance Complex
Bodie Creek
BALMER NORTH UNDERGROUND MINE (approx.)
Michel Creek
No. 3 Highway
Main Office
Tunnel
Conveyor
Coal Silos
Plant
Silos
Lagoons
PANEL 6 UNDERGROUND MINE (approx.)
Six Mile Creek
ELK RIVER
SPARWOOD
No 3 Highway
ELK RIVER
0
1000
2000
3000 Metres

FIGURE 17 WESTAR - BALMER DRAINAGE SYSTEM

Harmer Ridge to the east and Natal Ridge to the west; and Erickson Creek on the east which flows south through another U-shaped valley between the steep slopes of Erickson Ridge to the east and Natal Ridge to the west. Erickson Creek is a tributary of Michel Creek. Harmer Creek drains to Grave Creek and then the Elk River. Michel Creek is a tributary of the Elk River. The Balmer Operation is also drained by many smaller streams which flow into these main drainages.

Prior to 1985, approximately 90% of the company's annual Balmer coal production came from the surface mine. There are three distinct surface mining areas at the Balmer Operation with many subpits within these areas; Harmer area in the north, a middle area known as Adit 29S, and a southern area known as Adit 40. A new mine expansion is developing to the south of Adit 29S and is known locally as the A-Seam area.

The Balmer surface mine is a typical truck and shovel operation deploying electric shovels, trucks, front-end loaders, drills and a supporting fleet of crawlers, rubber-tired bulldozers, graders and other vehicles.

The average daily production in 1985 from the surface mine was 16 000 tonnes, but production has reached 20 000 tonnes of raw coal (1981). The potential annual output is about 8 million tonnes.

Until April 1985, the surface operation was augmented by an underground hydraulic mine (Panel 6) which was capable of producing approximately 1 million tonnes of raw coal annually.

The company also operated a smaller conventional room and pillar underground mine which used continuous miners to extract coal from the seam (Balmer North). This underground mine was closed in February 1986.

Water quality and flow data have been collected by various agencies from 1981 to 1986 and were examined in the following sections of this report to determine the inorganic nitrogen released from the Westar-Balmer Operation. Historical water quality data were generally limited to inorganic nitrogen concentrations, however, some data existed on total dissolved phosphorous, soluble reactive phosphorus and total phosphorous (1985-86 primarily). Flow data were collected at most sites at the time of sampling with the exception of Erickson Creek mouth and Michel Creek downstream of the operation. Only four flows were taken at Erickson Creek mouth in 1985-86 (at the time of the EP intensive surveys). Flow data at Michel Creek downstream were compiled by WSC. Nitrogen loadings at each site were calculated from the available data.

Flow and water quality data were examined at Harmer, Six Mile, Bodie and Erickson Creeks to quantify possible point sources of nitrogen and phosphorus contamination. Data from Michel Creek upstream and downstream of the operations were examined to determine the effect of various sources of nitrogen contamination on the receiving water and to quantify non-point contributions from the mine. The net nitrogen export from the mine was determined by summing the nitrogen export from Harmer Creek, Six Mile Creek and the difference between the upstream and downstream sites on Michel Creek. Bodie Creek and Erickson Creek data were not used in this calculation as they discharge to Michel Creek between the upstream and downstream sites. The Harmer Creek and Six Mile Creek loadings may have been overestimated since there were no background concentrations. Any nitrogen found in those streams was assumed to originate from explosives used at the mine.

3.5.1 Historical Nitrogen Export.

Between 1981 and 1984 water quality data were collected by the company primarily at six sites - Michel Creek upstream and downstream of the operations, Harmer Creek, Six Mile Creek, Bodie Creek, and Erickson Creek. Generally, samples were collected monthly in January, February and July to December and weekly from March to June. Samples were analysed for inorganic nitrogen species. Flows were determined on Harmer Creek, Six Mile Creek, Bodie Creek, and Michel Creek downstream at the time of sampling.

Flows at the Michel Creek downstream site were also determined by WSC. No flow data exists for Erickson Creek or for Michel Creek at the upstream site. Loadings at Michel Creek upstream were calculated using the flows from the Michel Creek downstream site which may have overestimated the loadings upstream of the mine. Measurement of the drainage areas of the two sites indicated the Michel Creek upstream site drainage area to be 90% of the downstream site area. Therefore, the error introduced in the loading calculation by using the same flows for both sites should be small.

WMB collected samples from the Michel Creek downstream site once a month between March and November, and analysed the samples for total inorganic nitrogen species.

Generally, from 1982 to 1984, the inorganic nitrogen concentrations and loadings at the Michel Creek downstream site, as determined by WMB, were lower than those determined by Westar Mining Ltd. (refer to Appendix VI).

A summary of inorganic nitrogen and total dissolved nitrogen concentrations and loadings and flows for the four effluents and two receiving waters are presented in Table 17. A complete data set is found in the separate Appendix report.

Examination of the historical data (1982 to 1984) for effluents from the Westar-Balmer mine indicated that Bodie Creek had the highest mean inorganic nitrogen concentration (9.1 mg/L) followed by Erickson Creek (5.7 mg/L) and Harmer Creek (3.2 mg/L). Values in Six Mile Creek (0.40 mg/L) were far lower than in any of the other creeks. Compared to other effluents in the Kootenay coal fields, the Bodie, Erickson, and Harmer Creek inorganic nitrogen concentrations were similar to those found at Fording Coal but much higher than levels found at Crows Nest Resources-Line Creek, Byron Creek Collieries, and Westar-Greenhills mines. Concentrations in Six Mile Creek at Westar-Balmer were more typical of levels found at the latter three mines.

Inorganic nitrogen loadings in the Westar-Balmer effluents were higher than those found at the other mines.

Historically the Harmer Creek effluent consistently had the highest mean inorganic nitrogen loadings at the Balmer minesite. The maximum loadings occurred in May and June and were coincident with peak flows (refer to Appendix VI).

The mean inorganic nitrogen concentrations in the receiving waters (Michel Creek upstream and downstream of the Balmer minesite) were fairly consistent from year to year at each of the sites. The mean inorganic nitrogen concentration at the upstream Michel Creek site for 1982 to 1984 was 0.26 mg/L while the downstream Michel Creek site was 0.49 mg/L.

Generally, the mean inorganic nitrogen concentrations in Michel Creek were considerably higher than those in the Byron Creek Collieries' receiving waters, slightly higher than in Line Creek, and considerably lower than in Fording Coal's receiving waters.

TABLE 17 SUMMARY OF WESTAR-BALMER EFFLUENT AND RECEIVING WATER NITROGEN DATA

EFFLUENTS	YEAR	NH_4/NH_3 (mg/L) Range (Mean)	NO_3 (mg/L) Range (Mean)	NO_2 (mg/L) Range (Mean)	TDN (mg/L) Range (Mean)	FLOW (m^3/s) Range (Mean)	INORGANIC N LOADING (kg/d) Range (Mean)	TDN LOADING (kg/d) Range (Mean)	NO. OF SAMPLES NH_3/NH_4	NO. OF SAMPLES NO_3	NO. OF SAMPLES NO_4
Hamer Creek	1982	ND-0.048 (0.127)	0.270-3.80 (2.510)	ND-0.032 (0.011)		0.453-4.816 (1.512)	29.7-1625.7 (371.465)		24	24	23
	1983	ND-0.372 (0.124)	ND-4.07 (3.272)	ND-0.022 (0.007)		0.320-3.258 (0.953)	69.9-513.4 (188.556)		12	12	12
	1984	ND-0.142 (0.079)	2.00-6.52 (3.459)	0.001-0.041 (0.008)		0.255-2.266 (0.829)	84.1-507.1 (220.304)		23	25	22
	1985	ND-0.370 (0.063)	1.39-7.95 (2.983)	0.001-0.30 (0.014)	1.8-5.70 (3.361)	0.317-3.116 (1.121)	71.86-1040 (273.153)	78.62-723.4 (325.12)	45	45	45
	1986*	<0.005-0.123 (0.046)	2.51-3.59 (3.149)	0.003-0.007 (0.005)	3.5-3.8 (3.65)	0.595-0.657 (0.628)	143.0-190.4 (171.340)	(198.7)	7	7	7
Bodie Creek	1982	ND-1.64 (0.546)	0.019-11.2 (4.522)	0.001-0.422 (0.068)		NF-0.3343 (0.147)	0.412-245.9 (77.034)		36	37	35
	1983	0.022-1.21 (0.427)	0.780-15.7 (7.326)	ND-0.839 (0.091)		0.0136-0.2096 (0.057)	1.8-204.3 (68.175)		33	33	32
	1984	ND-2.54 (0.472)	4.40-28.0 (13.803)	0.002-0.372 (0.083)		0.0113-0.2479 (0.049)	7.7-537.0 (80.973)		38	40	37
	1985	ND-6.82 (1.531)	2.75-49.0 (12.187)	0.001-1.26 (0.225)	5.5-78.0 (17.248)	0.0028-0.269 (0.087)	1.9-324.1 (89.295)	1.834-299.5 (97.228)	117	117	117
	1986*	0.01-0.176 (0.049)	0.261-8.40 (1.207)	<0.005-0.500 (0.052)	0.33-1.3 (0.597)	NF-0.2249 (0.064)	0.811-52.6 (10.864)	0.952-25.26 (6.484)	11	11	11

*Data to March 1986 only

CONTINUED...

TABLE 17 (Continued)

EFFLUENTS	YEAR	NH_4/NH_3 (mg/L)	NO_3 (mg/L)	NO_2 (mg/L)	TDN (mg/L)	FLOW (m^3/s)	INORGANIC N LOADING (kg/d)	TDN LOADING (kg/d)	NO. OF SAMPLES		
		Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	NH_3/ NH_4	NO_3	NO_4
Erickson Creek at mouth	1982	ND-0.480 (0.147)	0.04-7.80 (3.757)	ND-0.017 (0.007)					25	25	24
	1983	ND-1.38 (0.288)	3.20-5.49 (4.636)	ND-0.007 (0.002)					12	12	12
	1984	ND-0.262 (0.092)	3.95-14.7 (8.206)	ND-0.044 (0.008)					25	25	24
	1985	ND-5.43 (0.370)	2.60-11.2 (7.761)	ND-0.044 (0.013)	0.11-12.0 (9.05)	0.1119-0.351 (0.2103)	106.4-182.1 (139.13)	1.53-242.68 (139.18)	48	48	48
	1986*	< 0.010-0.848 (0.118)	7.50-15.7 (9.717)	0.002-0.067 (0.011)	9.9-11.0 (10.3)				9	9	9
Six Mile Creek	1982										
	1983	0.006-0.087 (0.047)	0.167-0.400 (0.285)	0.002-0.008 (0.006)		NF-0.0595 (0.016)	0.09-0.17 (0.137)		3	3	3
	1984	0.009-0.211 (0.089)	0.03-0.640 (0.372)	0.001-0.032 (0.006)		NF-0.0595 (0.025)	0.04-4.09 (1.238)		13	13	13
	1985	ND-0.250 (0.047)	ND-0.535 (0.240)	ND-0.30 (0.016)	0.05-0.72 (0.322)	NF-0.1116 (0.041)	0.024-4.31 (1.259)	0.081-4.821 (0.053)	33	33	33
	1986*	< 0.010-0.103 (0.029)	0.153-0.800 (0.389)	<0.005-0.008 (0.007)	3.4 (3.4)	0.0142-0.0943 (0.046)	0.20-6.7 (2.136)	4.17 (4.17)	5	5	5

*Data to March 1986 only

CONTINUED...

TABLE 17 (Continued)

RECEIVING WATERS	YEAR	NH_4/NH_3 (mg/L)	NO_3 (mg/L)	NO_2 (mg/L)	TDN (mg/L)	FLOW (m^3/s)	INORGANIC N LOADING (kg/d)	TDN LOADING (kg/d)	NO. OF SAMPLES		
		Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	NH_3/ NH_4	NO_3	NO_4
Michel Creek upstream	1982	ND–0.294 (0.170)	ND–0.100 (0.034)	ND–0.008 (0.005)		2.14–3.34 (2.70)	1.5–95.3 (23.65)		5	5	5
	1983	ND–0.600 (0.159)	ND–0.267 (0.153)	ND–0.013 (0.003)		1.91–24.2 (6.433)	0.40–356.3 (115.35)		11	11	11
	1984	ND–0.201 (0.079)	ND–0.560 (0.161)	ND–0.040 (0.008)		1.03–38.7 (11.306)	7.7–1231.0 (225.243)		42	46	40
	1985	ND–0.398 (0.027)	ND–0.300 (0.054)	ND–0.024 (0.005)	0.01–1.6 (0.111)	1.15–75.2 (16.024)	2.229–2008 (109.295)	7.43–841.9 (196.910)	118	118	118
	1986*	<0.005–0.28 (0.044)	<0.005–0.710 (0.086)	0.001–0.005 (0.004)	0.03–0.70 (0.133)	1.16–16.3 (4.34)	4.20–456.02 (63.98)	4.54–295.75 (53.68)	16	16	16
Michel Creek downstream	1981	ND–0.490 (0.095)	ND–0.810 (0.239)		0.139–0.591 (0.347)	1.98–83.0 (15.721)	14.5–2176.5 (370.424)	87.5–1687.7 (418.486)	21	21	
	1982	ND–0.169 (0.095)	0.005–1.02 (0.306)	ND–0.549 (0.074)	0.177–1.204 (0.377)	1.18–61.6 (13.969)	10.5–1538.6 (334.729)	32.9–942.0 (270.267)	34	35	28
	1983	ND–0.550 (0.109)	0.12–0.787 (0.369)	ND–0.025 (0.007)	0.176–0.444 (0.324)	1.838–98.5 (14.60)	33.9–836.4 (242.778)	43.9–851.7 (243.257)	18	18	11
	1984	ND–0.334 (0.082)	0.085–0.700 (0.408)	0.001–0.224 (0.017)	0.248–0.676 (0.451)	1.03–38.7 (10.511)	50.1–2002.8 (388.703)	66.1–741.4 (227.189)	32	34	22
	1985	ND–0.158 (0.029)	0.020–1.30 (0.342)	0.001–0.040 (0.007)	0.033–1.2 (0.435)	1.15–75.2 (15.782)	60.33–2014.0 (304.073)	46.27–1944.2 (424.519)	126	126	118
	1986*	0.003–0.182 (0.046)	0.202–1.03 (0.512)	< 0.001–0.03 (0.006)	0.26–1.5 (0.788)	1.16–16.3 (4.34)	74.07–440.92 (168.16)	67.15–433.38 (179.88)	18	18	18

*Data to March 1986 only

The inorganic nitrogen export from the Westar-Balmer minesite was calculated for both 1983 and 1984 by first subtracting the loading at the upstream Michel Creek site from that at the downstream Michel Creek site and then adding the loading from Harmer Creek and Six Mile Creek (Table 18). Bodie Creek and Erickson Creek loading data were examined as major point sources to Michel Creek but they were not used in the calculation of the overall loading.

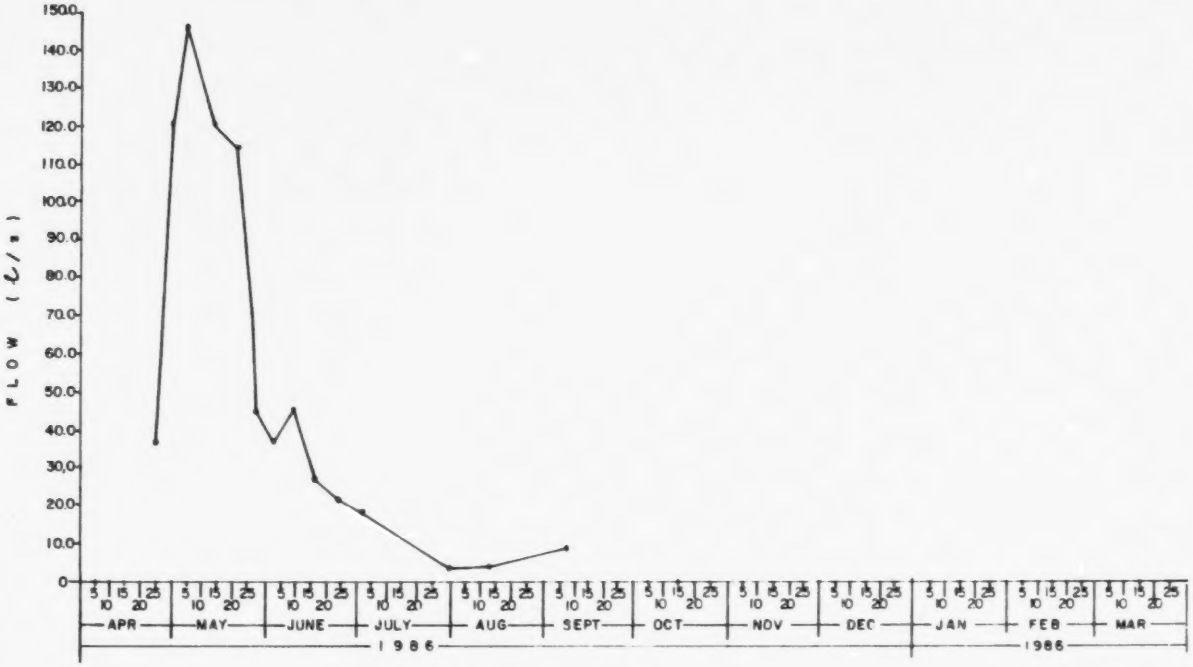
The total inorganic nitrogen export from the mine was 125 tonnes N in 1983 and 140 tonnes N in 1984 which represented 3.7% and 4.3% of the explosive used in those years, respectively. These exports were almost twice the releases predicted by the Pommen formula. The significance of this apparent underprediction is discussed in section 4.1. This mine apparently exported about 1.5 times the amount of nitrogen released from the Fording Coal mine and 37, 65, and 67 times that from the Crows Nest Resources-Line Creek, Byron Creek Collieries, and Westar-Greenhills mines, respectively.

3.5.2 1985-86 Nitrogen Export. Samples were analyzed at both Westar and EP laboratories in 1985-86 and at the WMB laboratory in 1985. The EP samples were those collected specifically for this study while the Westar samples were collected in compliance with provincial Waste Management Branch permits. The WMB samples were collected primarily to determine nutrient and algal growth trends in the Elk River Basin. One of the basins studied was Michel Creek and data were collected at the downstream site on this creek. Sampling, as required by permits or for the WMB study, was not as frequent as sampling for the EP study. Permit samples were collected monthly in January, February, and July - December, and weekly during March - June. WMB samples were collected monthly March through November. The EP sample frequency varied with site. Generally, the effluents were sampled weekly in April, May and June, and monthly thereafter with the exception of Bodie Creek and Michel Creek upstream and downstream. These latter sites were sampled daily (Monday through Friday) from April to June 1985 and weekly thereafter.

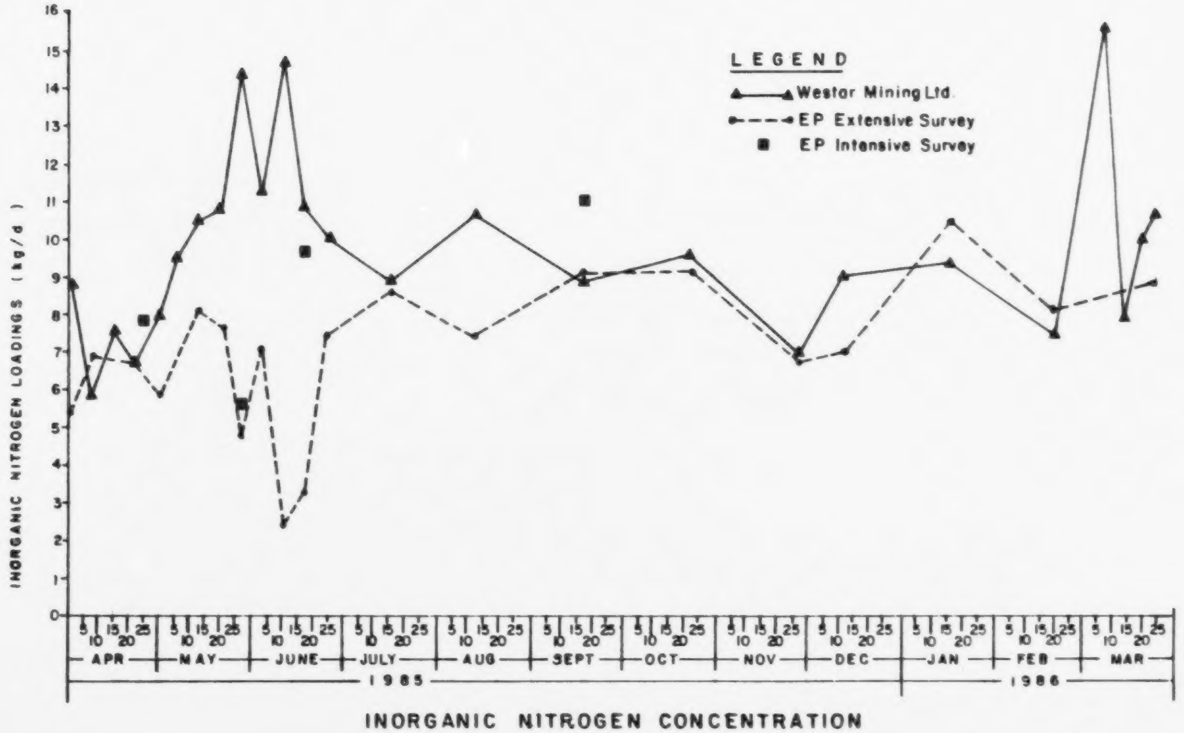
Samples were analysed for total inorganic nitrogen species and total dissolved nitrogen. Flows were taken at the time of sampling and loadings calculated. The results of these monitoring programs from all data sources are summarized in Table 17 and shown graphically in Figures 18 to 23.

TABLE 18 HISTORICAL INORGANIC NITROGEN EXPORT FROM WESTAR-BALMER MINE

	1983	1984
ANNUAL INORGANIC N LOADING (kg·N)		
Michel Creek upstream	33,447	52,725
Michel Creek downstream	100,720	132,932
Net Increase	67,243	80,180
Harmer Creek	54,478	59,491
Six Mile Creek	11	155
Net Export from Mine	124,732	139,826
EXPLOSIVE USE (kg·N) ANFO	2,729,717	2,577,156
Slurry	607,784	693,970
Total	3,337,501	3,271,126
ACTUAL N EXPORT AS % EXPLOSIVE	3.7%	4.3%
PREDICTED N EXPORT FROM MINE kg·N ANFO	27,297	25,772
Slurry	36,467	41,638
Total	63,764	67,410
PREDICTED N EXPORT AS % EXPLOSIVE	1.9%	2.1%
% ACTUAL N EXPORT OF PREDICTED	196%	207%

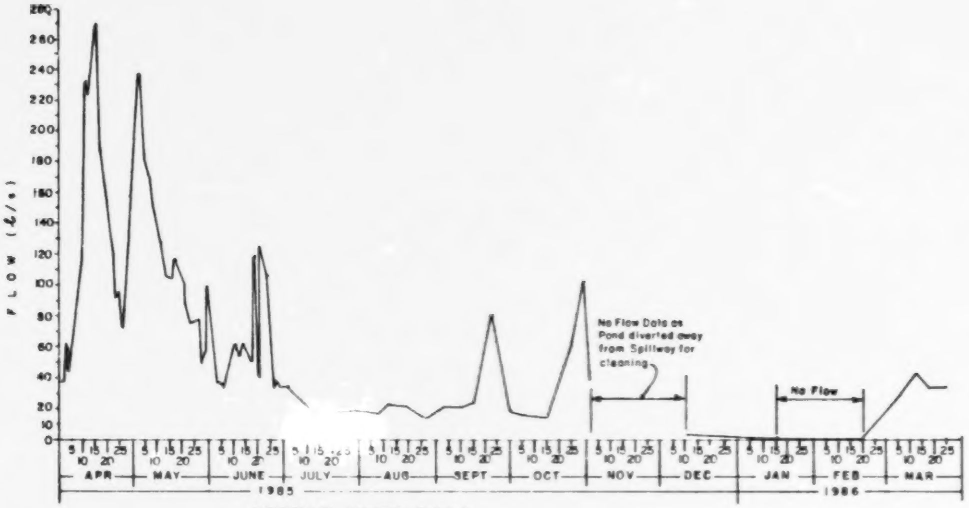


STREAM FLOW DATA

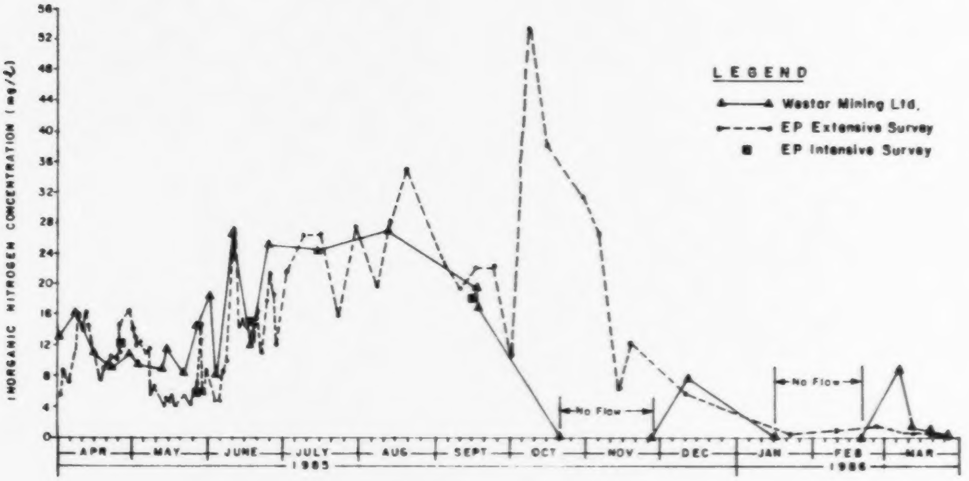


INORGANIC NITROGEN CONCENTRATION

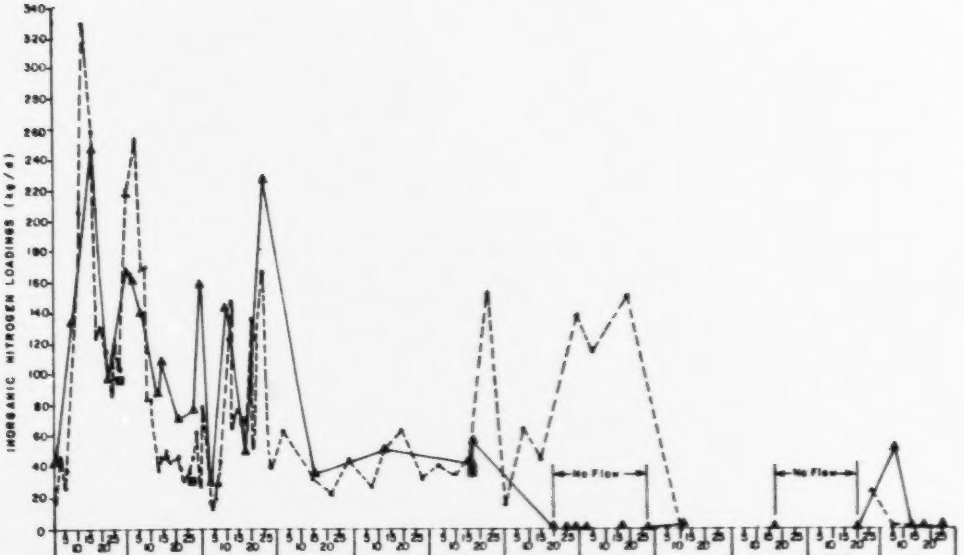
FIGURE 18 FLOW AND INORGANIC NITROGEN IN ERICKSON CREEK - APRIL 1985 TO MARCH 1986



STREAM FLOW DATA

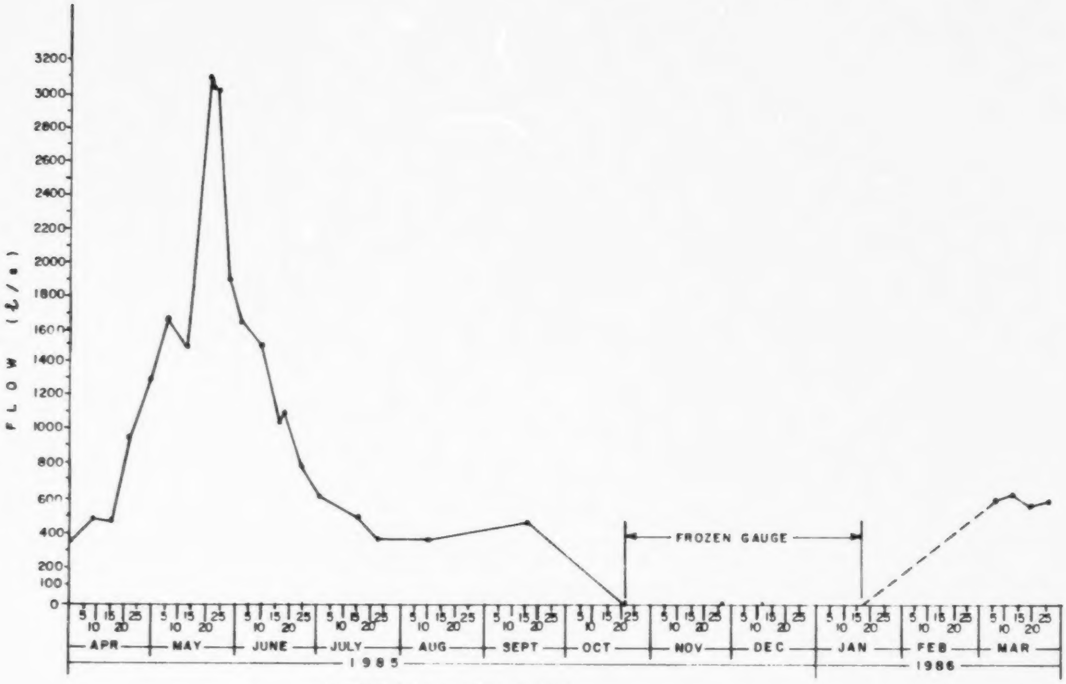


INORGANIC NITROGEN CONCENTRATION

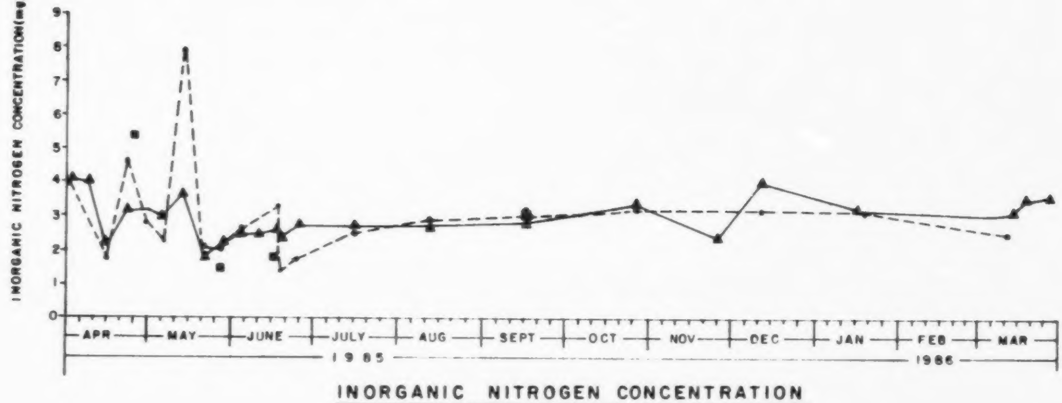


INORGANIC NITROGEN LOADINGS

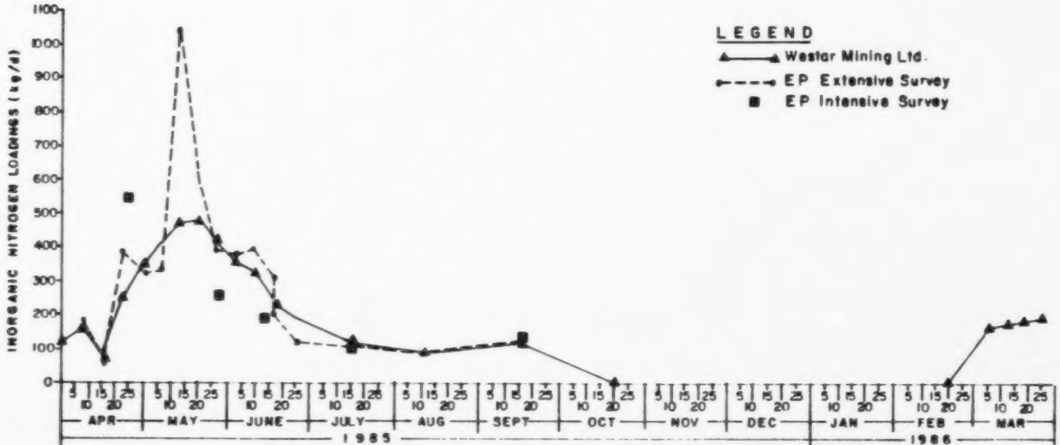
FIGURE 19 FLOW AND INORGANIC NITROGEN IN BODIE CREEK - APRIL 1985 TO MARCH 1986



STREAM FLOW DATA

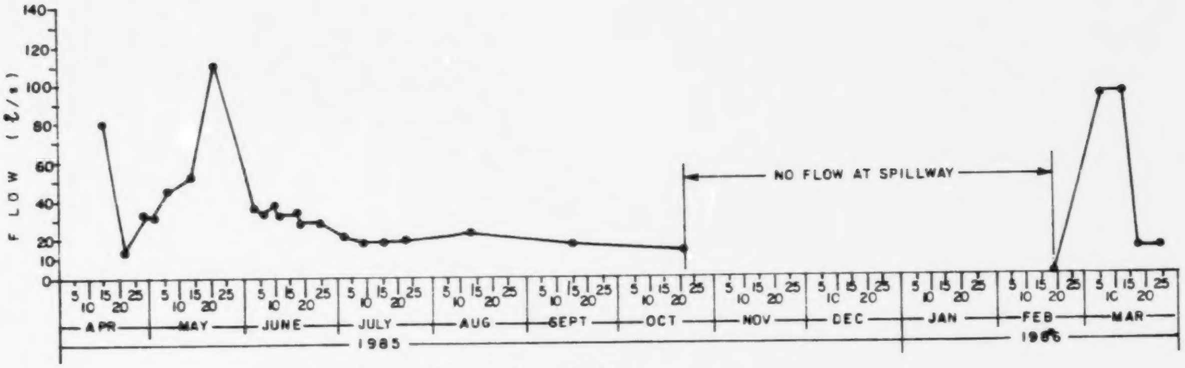


INORGANIC NITROGEN CONCENTRATION

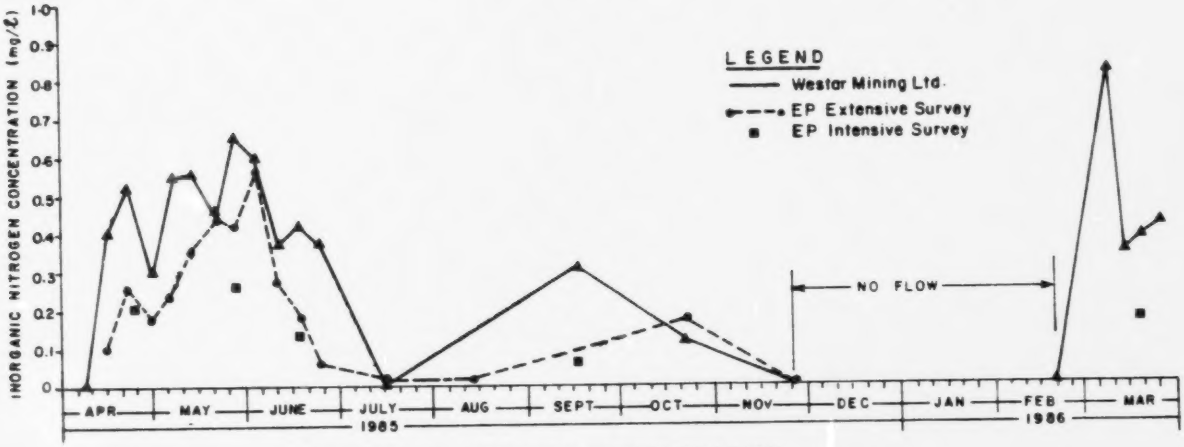


INORGANIC NITROGEN LOADINGS

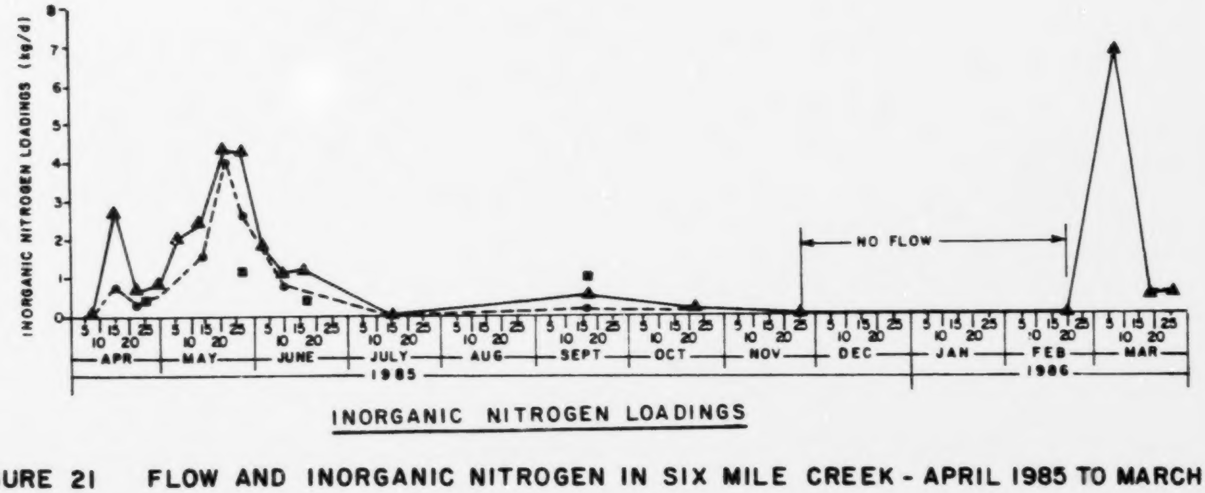
FIGURE 20 FLOW AND INORGANIC NITROGEN IN HARMER CREEK - APRIL 1985 TO MARCH 1986



STREAM FLOW DATA

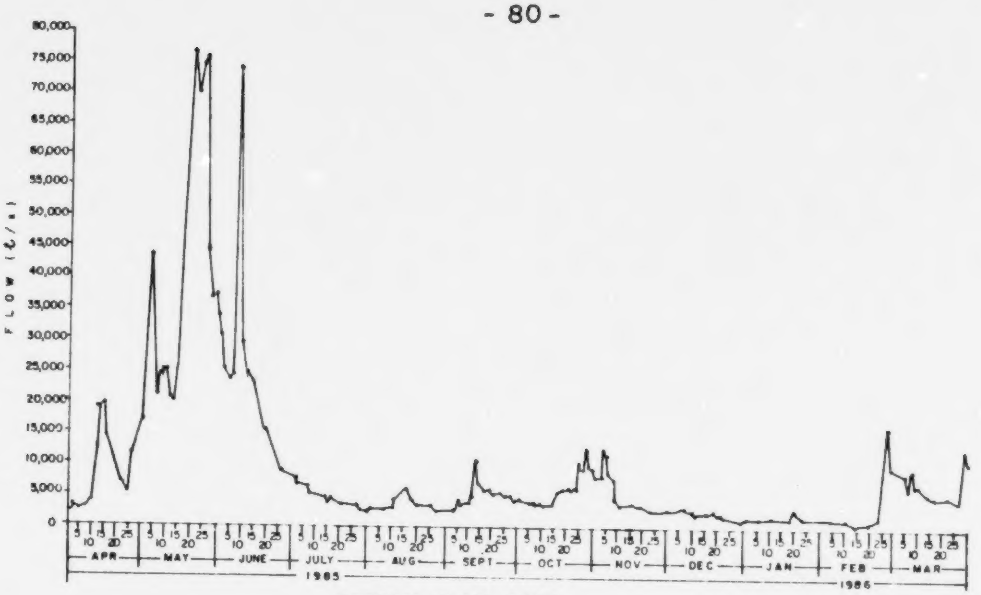


INORGANIC NITROGEN CONCENTRATION

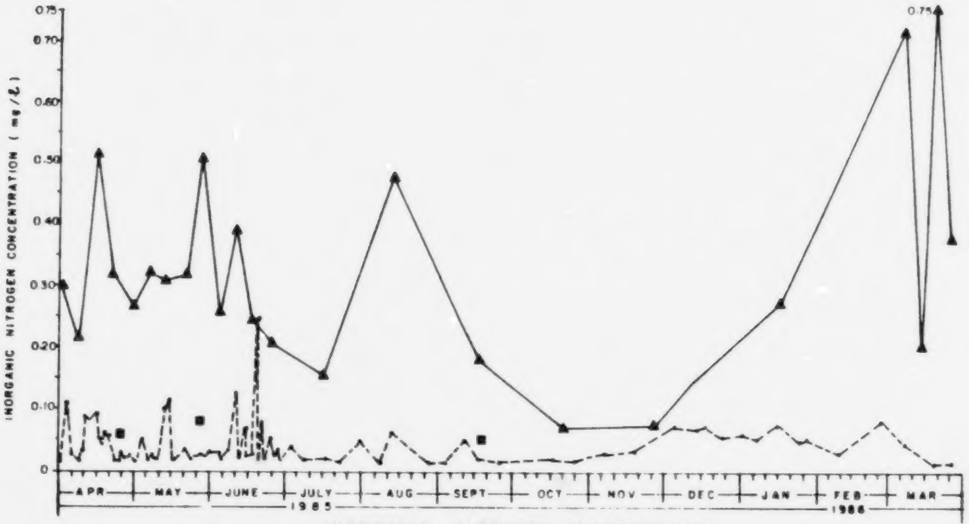


INORGANIC NITROGEN LOADINGS

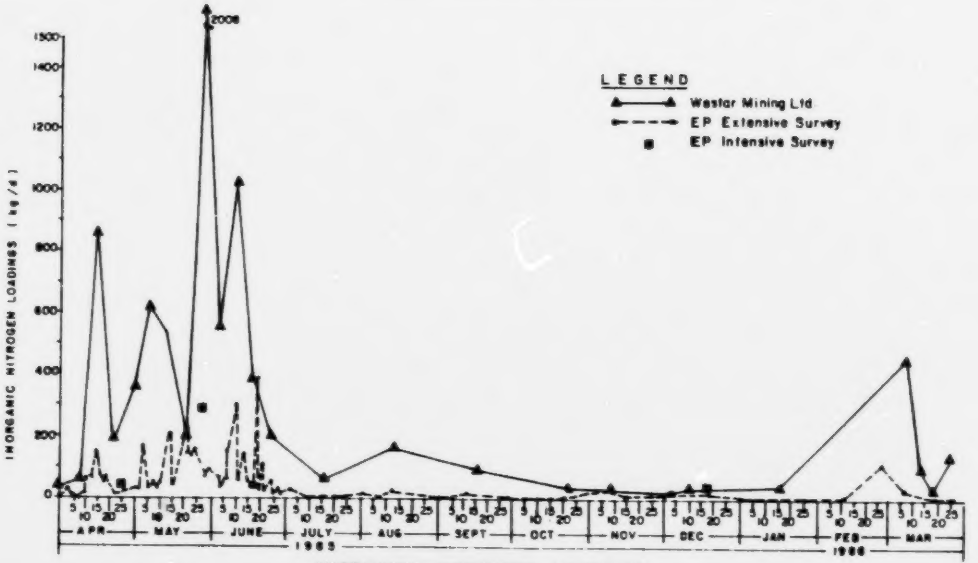
FIGURE 21 FLOW AND INORGANIC NITROGEN IN SIX MILE CREEK - APRIL 1985 TO MARCH 1986



STREAM FLOW DATA

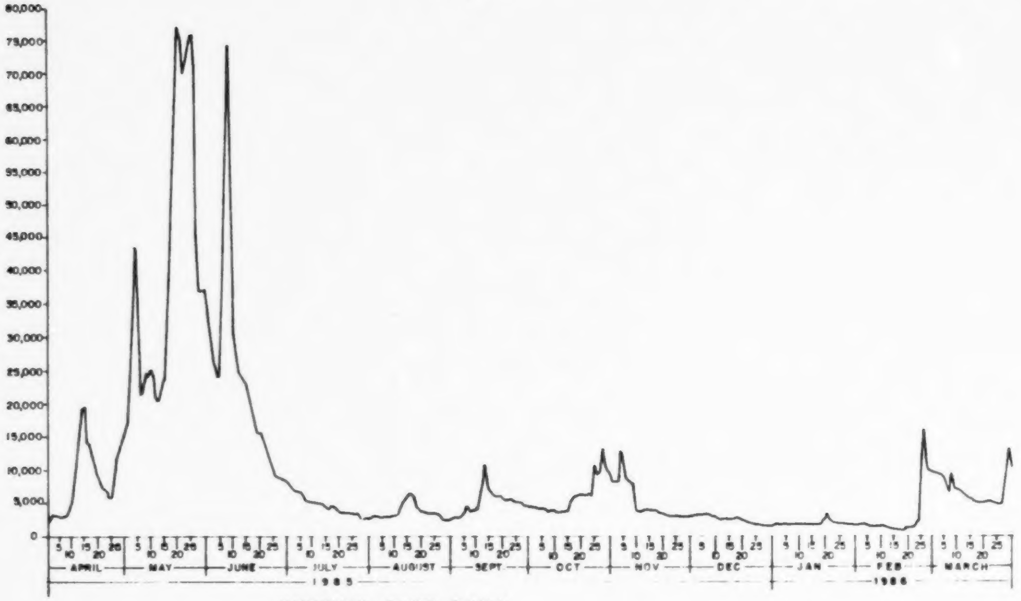


INORGANIC NITROGEN CONCENTRATION

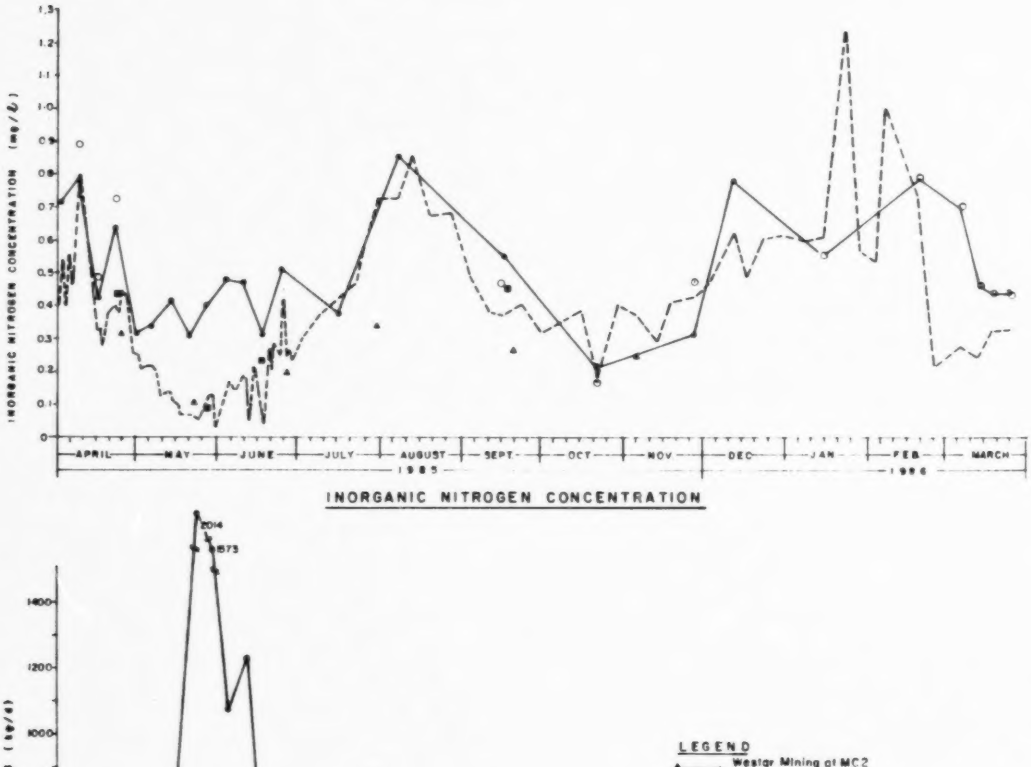


INORGANIC NITROGEN LOADINGS

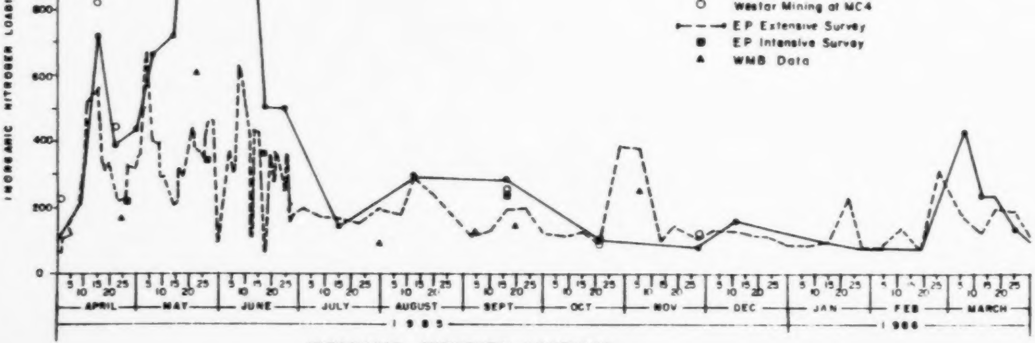
FIGURE 22 FLOW AND INORGANIC NITROGEN IN MICHEL CREEK UPSTREAM - APRIL 1985 TO MARCH 1986



STREAM FLOW DATA



INORGANIC NITROGEN CONCENTRATION



INORGANIC NITROGEN LOADINGS

FIGURE 23 FLOW AND INORGANIC NITROGEN IN MICHEL CREEK DOWNSTREAM - APRIL 1985 TO MARCH 1986

Complete data sets are found in the separate Appendix report.

The concentration of inorganic nitrogen species was significantly elevated in three of the four major streams draining the property (Bodie, Erickson and Harmer Creeks). There were discrepancies in inorganic nitrogen concentrations as measured by Westar Mining and EP. Inorganic nitrogen concentrations recorded by the company were considerably higher than those determined by EP in Erickson Creek mouth during late May and in early June; in Michel Creek upstream for most of the year; and in Michel Creek downstream in May and June. Nonetheless, levels fell within trends illustrated by EP data. The reason for the discrepancy is not known. The EP data base was primarily used in this analysis since it was more extensive than the company's.

Using the EP data base, Bodie Creek contained the highest concentration of inorganic nitrogen reaching about 53 mg/L. The maximum inorganic nitrogen concentration at Harmer Creek, Six Mile Creek, and Erickson Creek was 7.9 mg/L, 0.57 mg/L and 10.5 mg/L, respectively. In 1985-86, concentrations appeared to be slightly higher during the spring freshet compared to other times of the year in Harmer and Six Mile Creek. Elevated levels were found in Bodie Creek during late summer-early fall. Levels in Erickson Creek were fairly consistent throughout the year except in late May - early June when the concentrations decreased substantially due to dilution.

Concentrations of inorganic nitrogen in Michel Creek upstream of the mine were significantly lower for EP compared to company results. The reason for this discrepancy was not clear. In contrast, results for Michel Creek downstream of the mine agreed fairly well except in May - June 1985. The WMB inorganic nitrogen data collected at the Michel Creek downstream site correlated reasonably well with the inorganic nitrogen data collected by EP with one exception. On July 24, 1985, the WMB inorganic nitrogen was significantly lower than that determined by EP.

The maximum inorganic nitrogen reached in the upstream site on Michel Creek was 0.244 mg/L; it was 1.24 mg/L at the downstream site (EP data base). The inorganic nitrogen concentrations in Michel Creek at the upstream site were variable and peaked sporadically throughout the year. The inorganic nitrogen concentration at Michel Creek at the downstream site was low during May and June with peaks in April and August 1985 and January and February of 1986.

The concentration of total dissolved nitrogen was significantly elevated in all four creeks draining the property (effluent) with the exception of the Six Mile Creek. As with inorganic nitrogen concentrations, the maximum effluent total dissolved nitrogen concentration was found in Bodie Creek (78 mg/L). During 1985-86, maximum total dissolved nitrogen in Harmer Creek, Six Mile Creek and Erickson Creek was 5.7 mg/L, 3.4 mg/L, and 12 mg/L, respectively. In contrast to inorganic nitrogen concentrations, total dissolved nitrogen levels in Bodie Creek and Michel Creek downstream of the mine reached a maximum during the summer of 1985 and a near minimum during the spring freshet. Peak concentrations were also recorded in Michel Creek downstream in January-February 1986. The elevated concentrations during the summer months were likely associated with increased organic nitrogen from algal growth. Michel Creek upstream of the mine and Harmer Creek and Erickson Creek showed little variation in total dissolved nitrogen with the exception of a peak in January 1986 for Michel Creek upstream. Six Mile Creek exhibited slightly elevated total dissolved nitrogen concentrations during the spring freshet.

The proportion of inorganic nitrogen measured in the total dissolved nitrogen concentrations varied from a low of 44% for Six Mile Creek to 91% for Harmer Creek (Table 19). If inorganic nitrogen released from explosives was converted quickly to organic forms prior to arrival at downstream sampling sites, then estimates of explosives loss based on inorganic nitrogen would underestimate the true value. However, since the Harmer Creek and Michel Creek downstream sites recorded the two largest nitrogen exports and these sites had relatively high proportions of inorganic nitrogen in relation to the total dissolved nitrogen measured, that error was not expected to be more than 10-15%.

Of the four main streams draining the Westar-Balmer Mine (Harmer, Bodie, Six Mile and Erickson Creeks), Harmer Creek had, by far, the greatest flow; it reached about 3 100 L/s in late May 1985 (Figures 18-21). Flows from Six Mile Creek also peaked in late May. Maximum flows were reached in Bodie and Erickson Creeks in April and early May, respectively, while minimum flows were recorded in January 1986.

TABLE 19 PROPORTION OF INORGANIC NITROGEN OF TOTAL DISSOLVED NITROGEN CONCENTRATION - APRIL 1985 TO MARCH 1986*

LOCATION	MEAN INORGANIC N CONCENTRATION (mg/L)	MEAN TDN CONCENTRATION (mg/L)	INORGANIC N / TDN
Michel Creek upstream	0.191	0.281	68%
Michel Creek downstream	0.357	0.478	75%
Bodie Creek	12.5	16.1	78%
Erickson Creek	7.1	9.6	74%
Harmer Creek	3.1	3.4	91%
Six Mile Creek	0.223	0.511	44%

* EP data base used only

Flows in Michel Creek in 1985-86 followed the same trend as those for the input streams (Figures 22 and 23). However, since the data base was more extensive for these sites, minor variations in flows were apparent. The freshet involved at least four pulses superimposed on a general increase in flow as exemplified by the input stream data. Increases in flow (probably associated with precipitation events) were noted in August, September, October and November 1985 and February and March 1986.

Using the available flow data, inorganic nitrogen loadings at the four effluent and two receiving water sites were calculated using the company and EP data bases. Inorganic nitrogen loadings for the April 1985 to March 1986 period are graphically presented in Figures 18 to 23. A comparison of calculated inorganic nitrogen loadings for the April 1985 to March 1986 period is shown in Table 20. Results agreed quite well for the Bodie, Harmer and Six Mile Creek sites but there was a poor comparison between results for the two Michel Creek sites. Westar staff reported analytical difficulties in their ammonia measurements prior to 1986 (G. Mickelson, personal communications). Regardless, the inorganic nitrogen loading (net export from mine) was roughly the same using each data set. The net inorganic nitrogen export from the minesite for 1985-86 based on EP data was 101.3 tonnes/yr (Table 21).

TABLE 20 COMPARISON OF 1985-86 INORGANIC NITROGEN LOADINGS USING WESTAR AND EP DATA

LOCATION	INORGANIC N LOADING (kg/yr)	
	WESTAR	EP
Michel Creek upstream	65,100	10,300
Michel Creek downstream	114,400	70,900
Bodie Creek	24,400	27,900
Harmer Creek	46,300	40,600
Six Mile Creek	380	100

TABLE 21 1985-86 INORGANIC NITROGEN EXPORT FROM WESTAR-BALMER MINE

YEAR INORGANIC N LOADING (kg·N)	
Michel Creek upstream	10,300
Michel Creek downstream	70,900
Net Increase	60,600
Harmer Creek	40,600
Six Mile Creek	100
Net Export from Mine	101,300
EXPLOSIVE USE KG·N ANFO	3,570,000
Slurry	950,000
Total	4,520,000
ACTUAL N EXPORT AS % EXPLOSIVE	2.2%
PREDICTED N EXPORT FROM MINE KG·N ANFO	35,700
Slurry	57,700
Total	97,700
PREDICTED N EXPORT AS % EXPLOSIVE	2.2%
% ACTUAL N EXPORT OF PREDICTED	104%

The net export in 1985-86 was less than that found in 1983 and 1984 (125 tonnes/yr and 140 tonnes/yr) though more explosive was used in 1985-86. The actual nitrogen exported as a percentage of explosive was 3.7% in 1983, 4.3% in 1984, and 2.2% in 1985-86. The actual percent nitrogen loss recorded agreed quite well with the predicted value for 1985-86 according to the Pommen formula. The percentage actual nitrogen export of the predicted nitrogen for 1985-86 was 104%.

Loadings of inorganic nitrogen generally followed flow trends. Maximum loadings for all sites were achieved during the spring freshet.

3.5.3 **1985-86 Sources of Nitrogen.** Four EP intensive surveys were conducted to determine the source of nitrogen to receiving waters in 1985-86 at the Westar-Balmer Operations. The surveys were conducted on April 25, May 27-28, June 17-18, and September 16-17, 1985. Samples were taken at approximately ninteen locations, six of these locations were also monitored in the extensive survey. Samples were analyzed for total inorganic species and total dissolved nitrogen. Flows were taken at the time of sampling when and where possible. A summary of results from these four surveys is tabulated in Table 22. The range and mean shown represent four samples at each site except Harmer Oxidation (HOD) Ditch, Bodie Creek downstream HOD, Pool in Adit 29S, Bodie Creek at Silver Mile, Harmer Creek downstream Waste Rock, and Erickson Creek downstream Waste Rock (3 samples): and Harmer Creek Tributary and Erickson Creek Tributary (2 samples).

The inorganic nitrogen loadings and in some cases, concentrations, at each of these sites are graphically presented in Figures 24 to 27 for each survey conducted.

The total inorganic nitrogen concentrations determined in the EP intensive survey versus the extensive survey correlated well for the six sites duplicated (Bodie Creek, Harmer Creek, Six Mile Creek, Erickson Creek, and Michel Creek upstream and downstream of the operations) (Figures 18-23).

TABLE 22 SUMMARY OF WESTAR-BALMER 1985 EP INTENSIVE SURVEY NITROGEN RESULTS

LOCATION	FLOW (L/s) Range (Mean)	TDN (mg/L) Range (Mean)	NO_3 (mg/L) Range (Mean)	NH_3 (mg/L) Range (Mean)	NO_2 (mg/L) Range (Mean)	LOADING TDN (kg/d) Range (Mean)	LOADING INORG. N (kg/d) Range (Mean)
Hammer Oxid. Ditch (HOD)	-	5.9-11.0(8.7)	0.042-0.63(0.27)	2.6-6.2(4.1)	0.105-0.47(0.23)	-	-
Bodie Ck D/S HOD	1.1-1.3(1.2)	0.26-1.9(0.8)	0.20-1.3(0.6)	0.025-0.043(0.036)	0.005-0.055(0.027)	0.036-0.21(0.12)	0.031-0.155(0.093)
Seepage into Adit 29S	-	0.1-0.79(0.45)	0.09-74(18)	0.008-0.037(0.02)	0.005-0.008(0.006)	-	-
Pool in Adit 29S	-	29.0-58.0(38.7)	21.3-35.3(26.9)	1.32-7.8(3.8)	0.07-1.9(0.82)	-	-
Adit 29S Discharge	3.1-35(21)	11.0-37.0(21.8)	7.91-31.0(18.2)	0.47-4.1(2.1)	0.03-0.177(0.22)	3.49-81.2(54)	2.72-77.6(52)
Bodie Ck @ Silver Mile	24-62(46)	14.0-32.0(22.0)	8.67-28.0(17.7)	1.3-2.5(2.0)	0.392-0.7(0.54)	63-106(78)	51-97(71)
Bodie Ck Influent	42-43(42)	10.0-21.0(15.8)	5.61-17.6(12.9)	0.95-1.5(1.1)	0.15-0.493(0.36)	36-78(57)	25-70(47)
Bodie Ck Effluent	26-96(61)	7.9-19.0(13.2)	5.0-16.0(10.9)	0.802-2.1(1.2)	0.15-0.29(0.24)	42-100(68)	33-92(59)
Hammer Ck D/S Waste Rock	115-252(187)	11.0-18.0(14.7)	8.32-17.0(13.3)	0.014-0.094(0.041)	<0.005-0.016(0.009)	149-301(230)	145-286(204)
Hammer Ck Tributary	-	0.1-0.18(0.14)	0.08-0.021(0.051)	<0.005-0.009(0.007)	<0.005(0.005)	-	-
Hammer Ck Effluent	481-1290(1216)	2.3-5.6(3.5)	1.53-5.33(2.92)	<0.005-0.013(0.009)	<0.005-0.006(0.005)	133-553(346)	125-528(279)

TABLE 22 (Continued)

LOCATION	FLOW (L/s) Range (Mean)	TDN (mg/L) Range (Mean)	NO_3 (mg/L) Range (Mean)	NH_3 (mg/L) Range (Mean)	NO_2 (mg/L) Range (Mean)	LOADING TDN (kg/d) Range (Mean)	LOADING INORG. N (kg/d) Range (Mean)
Erickson Ck D/S Waste Rock	47-107(78)	18.0-53.0(34.3)	12.0-47.0(24.6)	<0.005-0.006(0.005)	0.005-0.9(0.30)	126-296(212)	104-193(136)
Erickson Ck @ Wier	65(65)	13.0-30.0(19.5)	7.48-24.6(15.8)	<0.005-0.015(0.010)	0.007-0.990(0.254)	73(73)	42(42)
Erickson Ck @ Mouth	112-351(210)	11.0-18.0(10.2)	5.3-11.0(8.4)	<0.005-0.006(0.005)	0.005-0.007(0.006)	106-243(177)	106-182(139)
Erickson Ck Tributary	-	0.28-38(19.1)	0.21-34.0(17.1)	0.006-0.016(0.011)	0.005-1.1(0.28)	-	-
Six Mile Effluent	18-54(33)	0.19-0.72(0.34)	0.048-0.247(0.153)	<0.005-0.011(0.006)	0.005-0.007(0.006)	0.29-3.3(1.2)	0.09-1.2(0.53)
Balmer N. Minewater	6-13(10)	2.3-3.6(3.2)	0.252-0.54(0.42)	2.1-2.51(2.35)	0.03-0.038(0.034)	1.2-4.0(3.0)	1.4-3.0(2.5)
Michel Ck U/S	5770-45400(18910)	0.07-0.14(0.095)	0.015-0.063(0.039)	<0.005-0.013(0.010)	0.005(0.005)	35-549(192)	28-286(99)
Michel Ck D/S	5770-45400(18910)	0.2-0.50(0.38)	0.081-0.430(0.28)	<0.005-0.025(0.016)	0.005-0.006(0.0053)	244-824(452)	214-375(296)

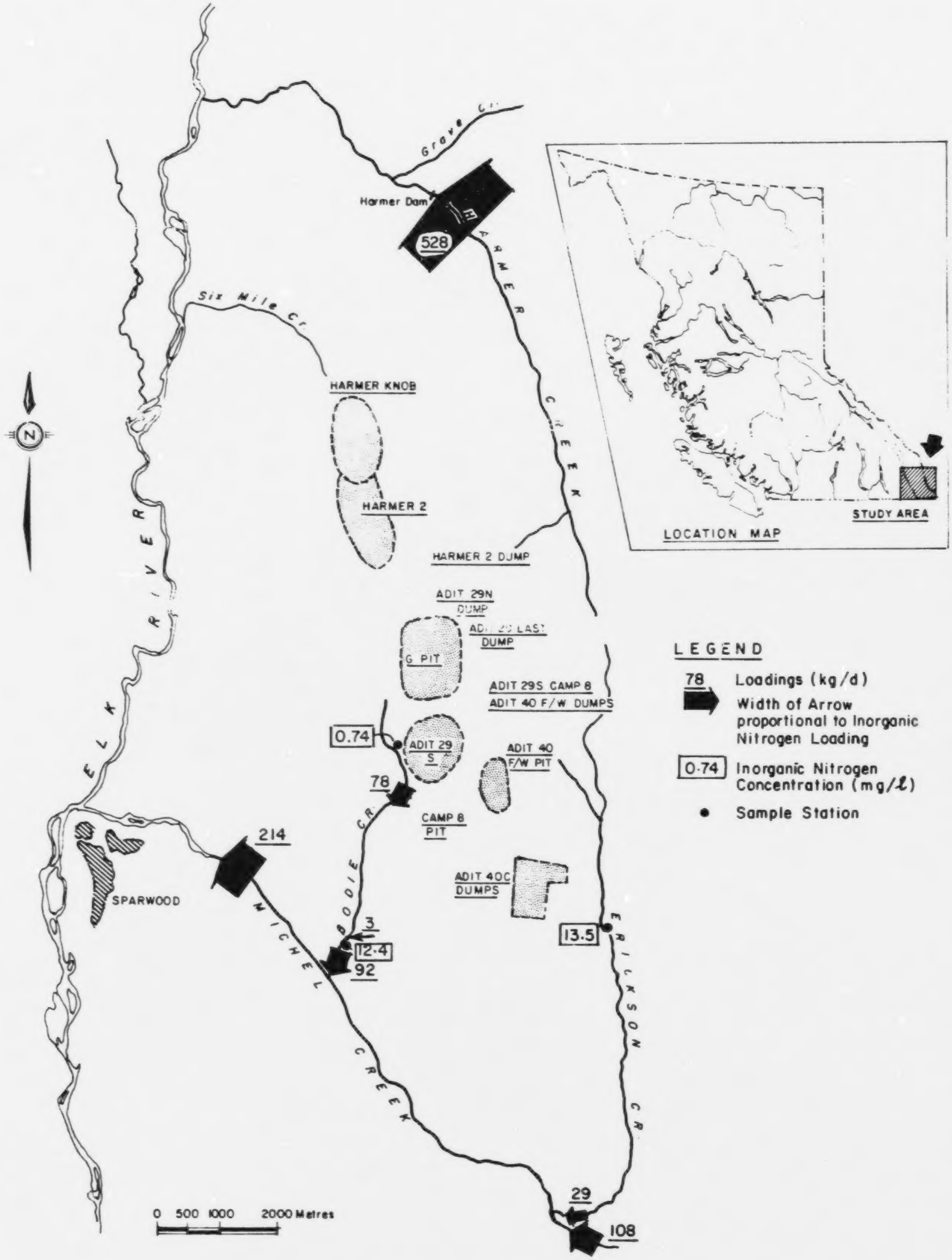

Grave Cr.
Harmer Dam
528
HARMER CREEK
Six Mile Cr.
HARMER KNOB
N
HARMER 2
HARMER 2 DUMP
ADIT 29N DUMP
ADIT 29 EAST DUMP
G PIT
ADIT 29S CAMP 8
ADIT 40 F/W DUMPS
0.74
ADIT 29 S
ADIT 40 F/W PIT
78
CAMP 8 PIT
BODIE CR.
214
SPARWOOD
ELK RIVER
ADIT 40C DUMPS
3
12.4
92
13.5
MICHEL CREEK
ERICKSON CR.
29
108
0 500 1000 2000 Metres
LOCATION MAP
STUDY AREA
LEGEND
78 Loadings (kg/d)
Width of Arrow proportional to Inorganic Nitrogen Loading
0·74 Inorganic Nitrogen Concentration (mg/ℓ)
● Sample Station

FIGURE 24 INORGANIC NITROGEN LOADINGS AND CONCENTRATIONS FOR EP INTENSIVE SURVEY - APRIL 25, 1985

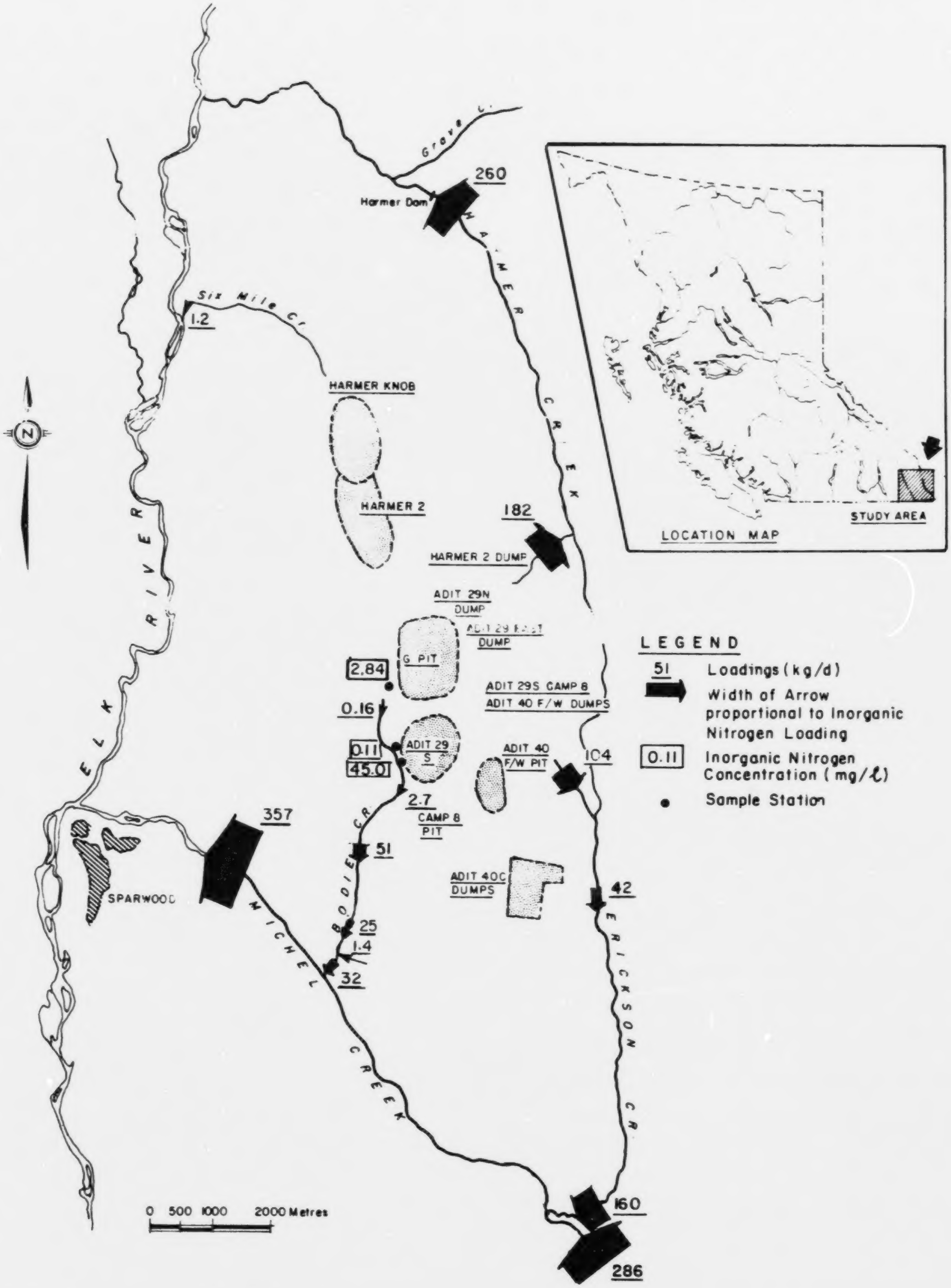

Grave Cr.
Harmer Dam
260
HARMER CREEK
Six Mile Cr.
1.2
HARMER KNOB
HARMER 2
182
HARMER 2 DUMP
ADIT 29N DUMP
ADIT 29 EAST DUMP
G PIT
2.84
0.16
0.11
45.0
ADIT 29 S
ADIT 29S CAMP 8
ADIT 40 F/W DUMPS
ADIT 40 F/W PIT
104
2.7
CAMP 8 PIT
357
51
ELK RIVER
N
SPARWOOD
ADIT 40C DUMPS
42
BODIE CR
25
1.4
32
MICHEL CREEK
ERICKSON CR
160
286
0 500 1000 2000 Metres
LOCATION MAP
STUDY AREA
LEGEND
51 Loadings (kg/d)
Width of Arrow proportional to Inorganic Nitrogen Loading
0.11 Inorganic Nitrogen Concentration (mg/ℓ)
Sample Station

FIGURE 25 INORGANIC NITROGEN LOADINGS AND CONCENTRATIONS FOR EP INTENSIVE SURVEY - MAY 27-28, 1985

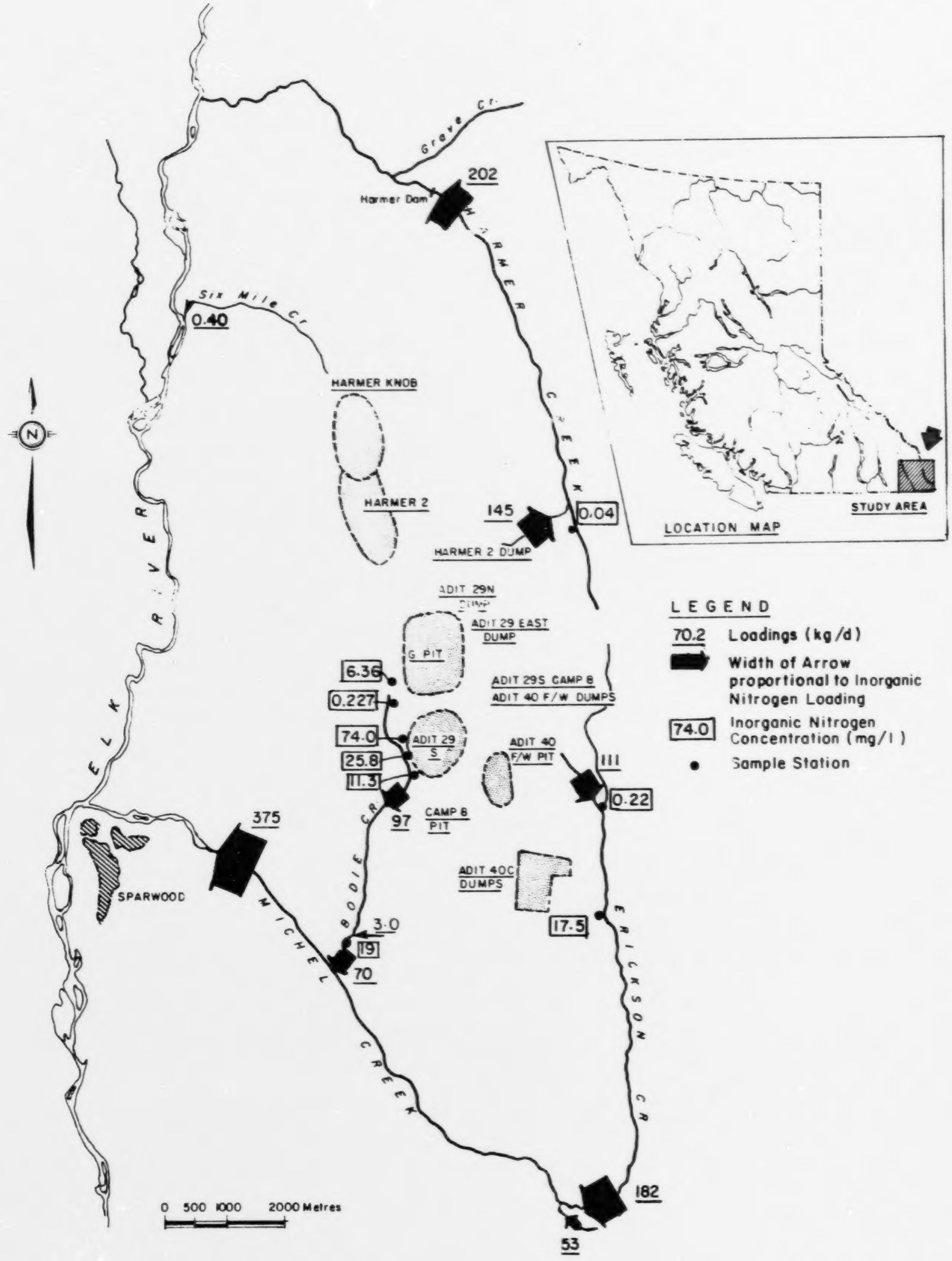

Grave Cr.
202
Harmer Dam
HARMER CREEK
Six Mile Cr.
0.40
HARMER KNOB
HARMER 2
145
0.04
HARMER 2 DUMP
LOCATION MAP
STUDY AREA
ELK RIVER
ADIT 29N DUMP
ADIT 29 EAST DUMP
G PIT
6.36
0.227
ADIT 29S CAMP 8
ADIT 40 F/W DUMPS
74.0
ADIT 29 S
25.8
11.3
ADIT 40 F/W PIT
111
0.22
97
CAMP 8 PIT
375
SPARWOOD
BODIE CR
ADIT 40C DUMPS
17.5
3.0
19
70
MICHEL CREEK
ERICKSON CR
182
53
0 500 1000 2000 Metres
LEGEND
70.2 Loadings (kg/d)
Width of Arrow proportional to Inorganic Nitrogen Loading
74.0 Inorganic Nitrogen Concentration (mg/l)
Sample Station

FIGURE 26 INORGANIC NITROGEN LOADINGS AND CONCENTRATIONS FOR EP INTENSIVE SURVEY - JUNE 17-18, 1985

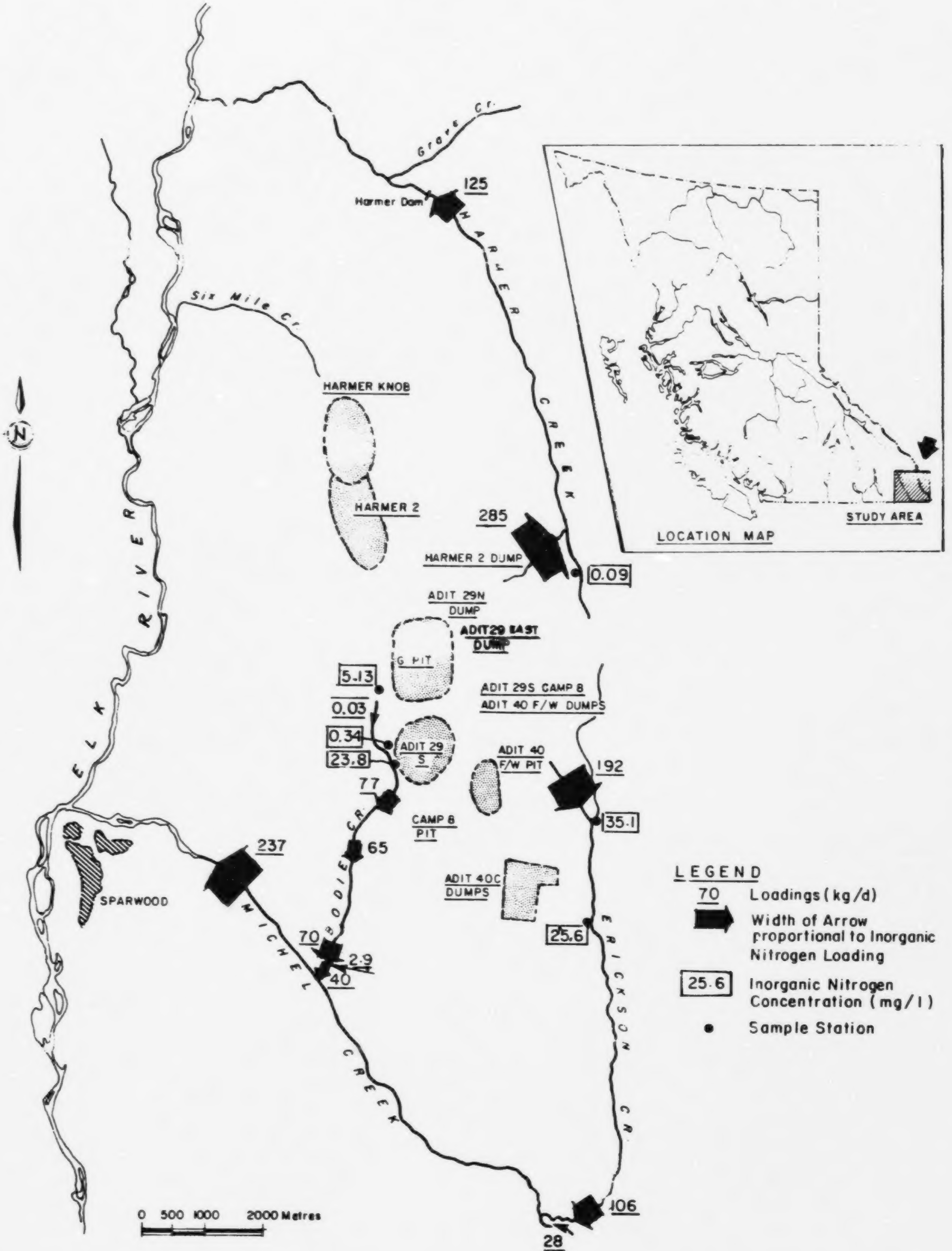

Grave Cr.
Harmer Dam
125
HARMER CREEK
Six Mile Cr.
HARMER KNOB
HARMER 2
285
HARMER 2 DUMP
0.09
ADIT 29N DUMP
ADIT29 EAST DUMP
G PIT
5.13
0.03
0.34
23.8
ADIT 29 S
ADIT 29S CAMP 8
ADIT 40 F/W DUMPS
ADIT 40 F/W PIT
192
35.1
77
CAMP 8 PIT
65
BODIE CR.
237
SPARWOOD
ELK RIVER
ADIT 40C DUMPS
25.6
70
2.9
40
MICHEL CREEK
ERICKSON CR.
106
28
0 500 1000 2000 Metres
N
LOCATION MAP
STUDY AREA
LEGEND
70 Loadings (kg/d)
Width of Arrow proportional to Inorganic Nitrogen Loading
25.6 Inorganic Nitrogen Concentration (mg/l)
● Sample Station

FIGURE 27 INORGANIC NITROGEN LOADINGS AND CONCENTRATIONS FOR EP INTENSIVE SURVEY - SEPTEMBER 16-17, 1985

In the Erickson Creek basin, using the EP intensive survey data, the concentration of inorganic nitrogen ranged from between 12 and 47 mg/L at a site located immediately below the waste rock dumps, to between 7.5 and 24.6 mg/L at the mid-point station, to between 5.3 and 11.0 mg/L at the mouth. The mean inorganic nitrogen concentrations from upstream to downstream were 24.7 mg/L, 15.8 mg/L and 8.4 mg/L, respectively. Thus, concentrations decreased with distance from the dumps probably as a result of dilution.

The mean inorganic nitrogen concentration immediately below the waste rock dump in Erickson Creek was nearly twice that found immediately below the dump in the Harmer Creek basin. The mean inorganic nitrogen concentration at the discharge point from Adit 29S into Bodie Creek was 18.25 mg/L. Thus, the highest mean inorganic nitrogen concentrations in the effluents were found in Erickson Creek immediately below the waste rock dumps.

The inorganic nitrogen loadings in Erickson Creek increased from the site immediately below the waste rocks dumps to the mouth for the May and June surveys and decreased for the September survey. There was insufficient data for comparison to the April survey. The reason for the decrease in loading for September is not clear although a similar decrease was noted in Harmer Creek loadings. The reduction may be related to the uptake of inorganic nitrogen by algae in the creek systems at that time of year. One sample (September survey) taken from the Erickson Creek tributary suggested that there was input from a source other than the waste rock dump. The source was not identified. Generally, the highest concentrations were found during the period of lowest flow (September sample) while the highest loadings were recorded during periods of high flow (May-June samples).

Total inorganic and dissolved nitrogen concentrations and loadings were examined at several sites along the length of Bodie Creek prior to its discharge into Michel Creek and at several potential point sources of nitrogen contamination (Harmer Oxidation Ditch Discharge, Adit 29S, and Balmer-North underground water).

Although Harmer Oxidation Ditch discharge itself had high concentrations of total dissolved nitrogen (mean 8.7 mg/L) and total inorganic nitrogen (mean 4.6 mg/L), the upper reaches of Bodie Creek generally were not affected by this source. Both total dissolved and

and inorganic nitrogen levels in the upper reaches of Bodie Creek were low (mean 0.85 mg/L and 0.64 mg/L, respectively). Seepage into the Adit 29S pit generally had low concentrations of total dissolved and total inorganic nitrogen with the exception of June 17 when the nitrate level was 74 mg/L. This level is thought to be in error as the total dissolved nitrogen for this date was only 0.1 mg/L. The mean inorganic nitrogen (excluding the June 17 result) was 0.41 mg/L and was comparable to the total dissolved nitrogen. A standing pool of water in Adit 29S and the discharge to Bodie Creek both had very high levels of total inorganic and total dissolved nitrogen (38.7 mg/L and 31.6 mg/L, respectively). The mean total dissolved and mean total inorganic nitrogen concentrations discharge from the pit to Bodie Creek were 21.8 mg/L and 20.6 mg/L. The other major source of water to Bodie Creek was the Balmer-North mine water; its mean total dissolved and mean total inorganic nitrogen concentrations were only 3.2 mg/L and 2.8 mg/L, respectively. Therefore, the primary source of nitrogen contamination in Bodie Creek was the mining activities in the Adit 29S pit.

The data from Bodie Creek indicated that, on average, the total dissolved nitrogen and total inorganic nitrogen concentrations decreased substantially downstream. This is understandable as no new major sources entered the system between the pit and mouth and there was substantial dilution. However, the loading data at these same sites were inconsistent. This may have been due, in part, to fluctuations in discharge from the Adit 29S pit and/or the Balmer underground mine water. Flows into and out of the Bodie Creek treatment pond were known to have varied substantially due to changing seepage rates within the pond system.

The increase in inorganic nitrogen in Michel Creek downstream as compared to upstream can be explained, in part, by the nutrient input from Erickson and Bodie Creeks. In general, Erickson and Bodie Creeks could account for 100%, 78%, and 70% of the Michel Creek increase in April-May, June, and September, respectively. Thus, Erickson and Bodie Creeks were the major source of nitrogen to Michel Creek. The sum of upstream Michel Creek, Bodie Creek, and Erickson Creek loadings were within 7 - 34% of the downstream loadings; two were higher and two lower. This agreement is reasonable given the possible temporal variability in concentration and the quality of the flow data.

Most of the inorganic nitrogen in the Bodie Creek system was in the nitrate form. The percentage of nitrate in the inorganic nitrogen fraction throughout the system did not vary substantially suggesting there was little conversion of ammonia to nitrate by nitrification below Adit 29S. Overall concentrations in the system varied seasonally. High concentrations of inorganic nitrogen were found in June - October when flows were lower. The loadings were generally higher in the spring coinciding with peak flows.

For Six Mile Creek, concentrations and loadings of both total dissolved and total inorganic nitrogen were extremely low. The mean total dissolved nitrogen and mean total inorganic nitrogen concentration were only 0.34 mg/L and 0.17 mg/L, respectively. The mean dissolved nitrogen loading was 1.2 kg/d and the mean inorganic nitrogen loading was 0.53 kg/d. Therefore, Six Mile Creek contributed only a small proportion of the total dissolved and total inorganic nitrogen load to the overall net export of nitrogen from the Westar-Balmer Operation.

Total inorganic and dissolved nitrogen concentrations and loadings were examined at several sites along Harmer Creek. Sampling of the Harmer Creek tributary that is not in the vicinity of the waste rock dumps indicated extremely low levels of inorganic nitrogen (mean 0.14 mg/L) and total dissolved nitrogen (mean 0.063 mg/L). Thus, this tributary was not considered a source of nitrogen contamination to the Harmer Creek system.

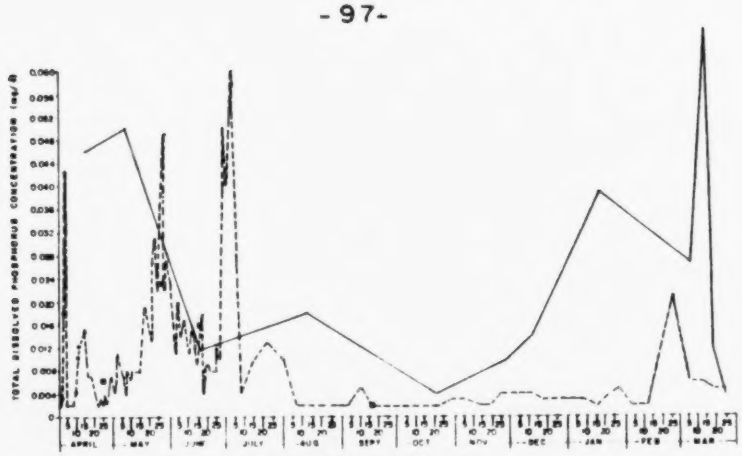
The main branch of Harmer Creek, however, has its headwaters located in a waste rock dump site. Sampling the creek immediately below these waste rock dumps indicated quite high levels of total dissolved nitrogen and total inorganic nitrogen (14.7 mg/L and 13.3 mg/L, respectively). The inorganic nitrogen and total dissolved nitrogen loadings below the Harmer waste rock dump ranged between 145 - 285 kg/d and 149 - 301 kg/d, respectively. At the Harmer Creek spillway the inorganic nitrogen and total dissolved nitrogen loadings ranged between 125 - 528 kg/d and 133 - 553 kg/d, respectively. These loadings were considerably higher than those calculated at the site immediately below the Erickson Creek waste rock dump, at the mouth of Erickson Creek, or at the Bodie or Six Mile Creek sites. The Harmer waste rock dumps were, therefore, determined to be the largest single contributor of nitrogen from the Westar-Balmer operation.

If each nitrogen species (NH_3, NO_3, NO_2) was expressed as a percentage of the total inorganic nitrogen concentration at Harmer Creek below the waste rock dump and Harmer Creek spillway for each of the four surveys, then the species distribution changed only slightly (< 1%) from the upstream to the downstream site. Generally, the NO_3 decreased slightly and the NO_2 and NH_3 increased slightly. Little nitrification occurred in the system.

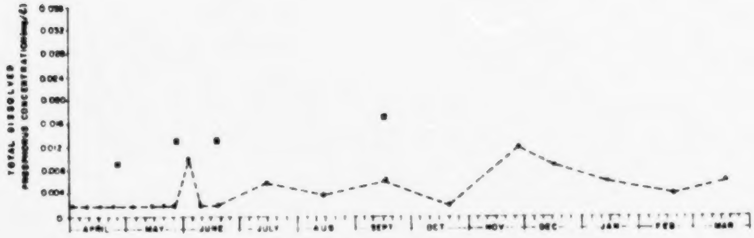
The intensive survey data for Michel Creek upstream and downstream of the operations indicated that the mean total dissolved nitrogen and inorganic nitrogen concentrations increased from upstream to downstream (mean total dissolved nitrogen was 0.095 mg/L upstream and 0.375 mg/L downstream, mean inorganic nitrogen was 0.054 mg/L upstream and 0.303 mg/L downstream). The mean total dissolved nitrogen and inorganic nitrogen loading increased about 2.3 times and 3 times, respectively, and confirmed observations made during the extensive survey.

3.5.4 1985-86 Phosphorus Export. Phosphorus species data were available for 1981 to 1986 for Michel Creek downstream of the mine. Michel Creek upstream had data for 1984 to 1986, but all other sites had data for 1985-86 only. The 1985-86 data base was the most extensive and will be the one considered in this section.

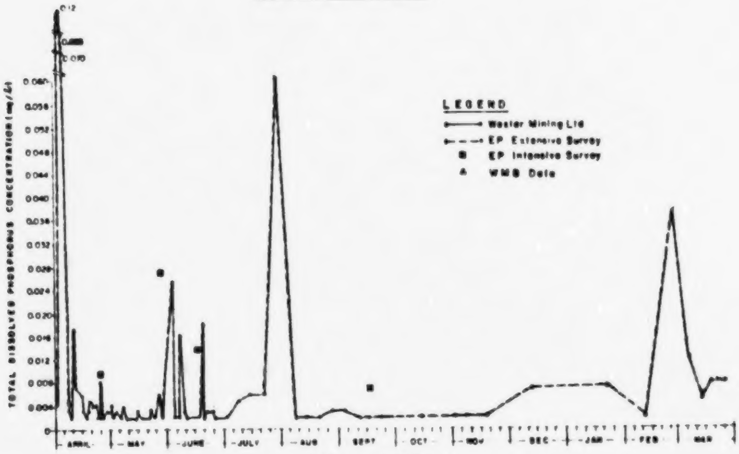
EP extensive survey TDP concentrations for Michel Creek drainages and Six Mile and Harmer Creeks are shown in Figures 28 and 29. Results obtained by Westar Mining Ltd. for Michel Creek are generally higher than those obtained by EP or WMB. EP and WMB results were in reasonable agreement. TDP concentrations tended to be higher during the freshet and winter compared to summer and fall. This may have reflected rapid uptake of phosphorus by algae during the peak growing season. Concentrations of TDP upstream of the mine were generally higher than the downstream site. Erickson Creek did not appear to contain elevated TDP concentrations but peaks were observed in Bodie Creek. With the exception of peaks in early April, June, late July, and late February, concentrations of TDP in Bodie Creek were lower than values found in Michel Creek upstream of mine operations. Concentrations of TDP in Harmer and Six Mile Creeks (Figure 29) were lower than those observed in the Michel Creek system.



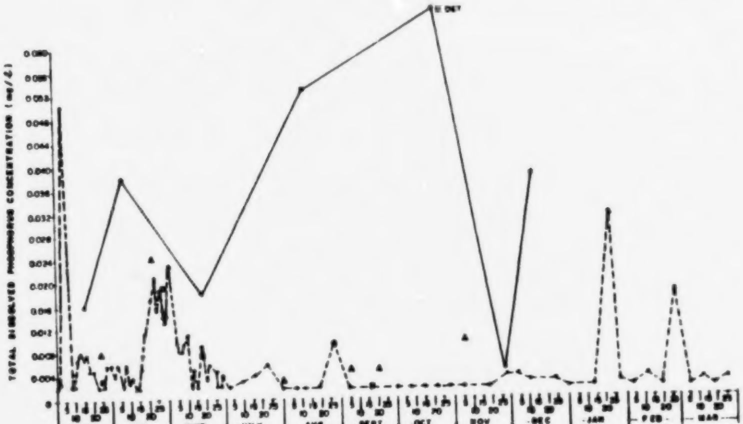
MICHEL CREEK UPSTREAM OF OPERATIONS



ERICKSON CREEK



BODIE CREEK



MICHEL CREEK DOWNSTREAM OF OPERATIONS

FIGURE 28 TOTAL DISSOLVED PHOSPHORUS CONCENTRATIONS - MICHEL CREEK DRAINAGES - APRIL 1985 TO MARCH 1986

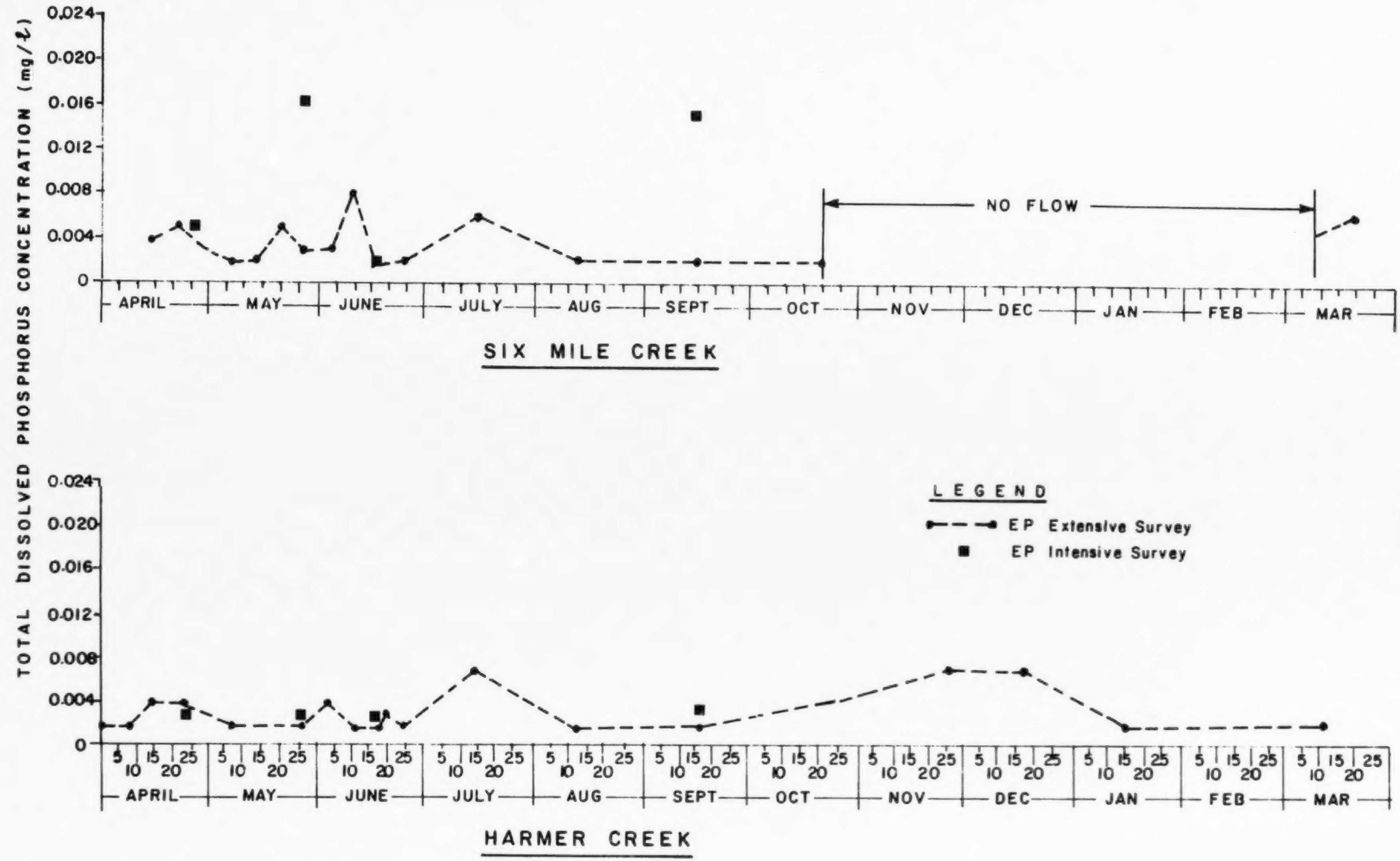


FIGURE 29 TOTAL DISSOLVED PHOSPHORUS CONCENTRATIONS - SIX MILE AND HARMER CREEKS - APRIL 1985 TO MARCH 1986

Mean TDP, SRP, and TP concentrations based on all data sources for the four effluent creeks and Michel Creek upstream and downstream of the mine are shown in Table 23. In general, there was little change in the mean TDP concentrations upstream and downstream of the mine in Michel Creek in 1985 (0.012 mg/L and 0.011 mg/L, respectively) and in 1986 (0.006 mg/L for both). The four effluent streams contained lower levels of TDP with the exception of Bodie Creek in 1986 (0.011 mg/L).

The SRP mean concentration was roughly the same at the downstream compared to the upstream Michel Creek site. Levels of SRP in all three effluent streams except Bodie Creek in 1985 and 1986 (0.018 mg/L and 0.008 mg/L, respectively) and in Erickson Creek in 1986 (0.005 mg/L) were lower than in the receiving water.

The downstream mean TP concentration was lower in 1985 and about the same in 1986 compared to the upstream location. The mean concentration of TP was significantly higher in Bodie Creek and slightly elevated in Six Mile Creek compared to the receiving water sites. Erickson and Harmer Creek mean TP concentrations were lower than receiving waters.

A comparison of the levels of phosphorus species in the effluent streams and receiving waters suggested that Balmer mine was not a significant contributor of TDP; however, the SRP and TP released from Bodie Creek may have had the potential to affect water quality in Michel Creek.

Loadings of TDP, SRP, and TP in the four effluent streams were very small relative to the loadings in Michel Creek upstream of the mine. Differences in loadings reflected changes in concentration and flow on the sampling days. However, results did indicate a slight increase in TDP in 1985 and TP in 1986 at the downstream site. Total dissolved phosphorus decreased in 1986, TP decreased in 1985, and SRP decreased both years.

Variations in seasonal sampling frequency may have affected the above analysis. As with the Line Creek phosphorus results, data from the EP extensive survey at the Westar-Balmer mine were divided into quarters (Table 24). With these data, the mean TDP, SRP, and TP concentrations were generally lower at the downstream Michel Creek site compared to the upstream location. Levels of TDP in effluent streams were generally lower than the Michel Creek sites with the exception of Erickson and Harmer Creeks in October - December and Bodie Creek in January - March. Overall results for

TABLE 23 SUMMARY OF WESTAR-BALMER EFFLUENT AND RECEIVING WATER PHOSPHORUS DATA

EFFLUENTS	YEAR	TDP (mg/L)	SRP (mg/L)	TP (mg/L)	TDP LOADING (kg/d)	SRP LOADING (kg/d)	TP LOADING (kg/d)	NO. OF SAMPLES		
		Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	TDP	SRP	TP
Hammer Creek	1982							0	0	0
	1983							0	0	0
	1984							0	0	0
	1985	<0.002-0.007 (0.003)	<0.002-0.005 (0.003)	<0.002-0.087 (0.015)	0.063-0.572 (0.274)	0.063-0.572 (0.266)	0.231-23.31 (2.018)	23	19	23
	1986*	<0.002-<0.002 (<0.002)	<0.002-0.004 (0.003)	<0.002-0.006 (0.004)	(0.114)	(0.114)	(0.114)	2	2	2
Bodie Creek	1982							0	0	0
	1983							0	0	0
	1984							0	0	0
	1985	<0.002-0.12 (0.009)	<0.002-0.92 (0.018)	<0.002-3.0 (0.268)	0.002-0.64 (0.051)	0.001-6.415 (0.137)	0.002-68.43 (2.318)	86	83	86
	1986*	<0.002-0.037 (0.011)	<0.002-0.037 (0.008)	<0.002-0.718 (0.120)	0.018-0.713 (0.171)	0.006-0.719 (0.161)	0.04-13.95 (2.892)	7	7	7

*Data to March 1986 only

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TABLE 23 (Continued)

EFFLUENTS	YEAR	TDP (mg/L) Range (Mean)	SRP (mg/L) Range (Mean)	TP (mg/L) Range (Mean)	TDP LOADING (kg/d) Range (Mean)	SRP LOADING (kg/d) Range (Mean)	TP LOADING (kg/d) Range (Mean)	NO. OF SAMPLES TDP	NO. OF SAMPLES SRP	NO. OF SAMPLES TP
Erickson Creek at mouth	1982							0	0	0
	1983							0	0	0
	1984							0	0	0
	1985	<0.002-0.017 (0.006)	<0.002-0.01 (0.005)	0.005-0.031 (0.015)	0.125-0.394 (0.232)		0.164-0.4854 (0.278)	22	18	22
	1986*	0.004-0.006 (0.005)	<0.002-0.011 (0.005)	<0.002-0.016 (0.006)				3	3	3
Six Mile Creek	1982							0	0	0
	1983							0	0	0
	1984							0	0	0
	1985	<0.002-0.016 (0.005)	<0.002-0.032 (0.006)	<0.002-0.143 (0.043)	0.002-0.074 (0.016)	0.003-0.125 (0.025)	0.005-1.427 (0.197)	19	15	19
	1986*	0.006 (0.006)	<0.002 (0.002)	0.031 (0.031)	0.007 (0.007)	0.002 (0.002)	0.038 (0.038)	1	1	1

*Data to March 1986 only

CONTINUED...

TABLE 23 (Continued)

RECEIVING WATERS	YEAR	TDP (mg/L)	SRP (mg/L)	TP (mg/L)	TDP LOADING (kg/d)	SRP LOADING (kg/d)	TP LOADING (kg/d)	NO. OF SAMPLES		
		Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	Range (Mean)	TDP	SRP	TP
Michel Creek upstream	1982							0	0	0
	1983							0	0	0
	1984	ND-0.048 (0.019)			0.47-9.5 (3.222)			9	0	0
	1985	ND-0.050 (0.012)	<0.002-0.024 (0.007)	<0.002-0.399 (0.033)	0.297-193.6 (23.594)	0.295-149.9 (17.688)	0.506-1006.0 (76.662)	101	89	93
	1986*	<0.002-0.021 (0.006)	<0.002-0.014 (0.003)	<0.002-0.127 (0.017)	0.263-29.57 (3.97)	0.263-19.72 (2.49)	0.263-178.86 (18.73)	11	11	11
Michel Creek downstream	1981	0.006-0.019 (0.011)	0.004-0.015 (0.007)	0.007-0.066 (0.022)	1.25-83.7 (23.674)	0.833-61.7 (18.16)	1.46-290.8 (61.136)	7	7	7
	1982	0.006-0.022 (0.009)	0.003-0.030 (0.009)	0.006-0.066 (0.020)	0.66-117.1 (16.867)	1.34-95.8 (19.95)	0.66-351.3 (73.037)	8	8	8
	1983	0.005-0.018 (0.010)	0.003-0.011 (0.006)	0.007-0.046 (0.018)	1.00-41.34 (12.909)	0.60-27.6 (7.927)	1.43-126.8 (27.7)	6	6	6
	1984	ND-0.077 (0.017)	0.003-0.014 (0.005)	0.004-0.041 (0.013)	0.42-71.75 (9.559)	0.31-41.9 (6.006)	0.73-122.6 (18.439)	15	9	9
	1985	ND-0.067 (0.011)	0.001-0.029 (0.006)	<0.002-0.162 (0.027)	0.295-145.4 (29.477)	0.243-143.7 (15.37)	0.295-993.9 (54.926)	108	100	100
	1986*	<0.002-0.031 (0.006)	< 0.002-0.014 (0.003)	<0.002-0.149 (0.018)	0.200-25.35 (3.19)	0.200-19.72 (2.168)	0.200-209.84 (19.52)	12	12	12

*Data to March 1986 only

TABLE 24 MEAN TDP, SRP, AND TP CONCENTRATIONS BY QUARTER 1985-86 EP DATA* WESTAR-BALMER

LOCATION	MEAN CONCENTRATION (mg/L)				MEAN FOR YEAR
	APRIL-JUNE	JULY-SEPT.	OCT.-DEC.	JAN.-MAR.	
TDP					
Michel Ck u/s	0.014	0.008	0.003	0.006	0.008
Michel Ck d/s	0.008	0.003	0.003	0.006	0.005
Bodie Ck	0.009	0.007	0.003	0.011	0.008
Erickson Ck	0.003	0.005	0.008	0.005	0.005
Harmer Ck	0.003	0.004	0.005	0.002	0.004
Six Mile Ck	0.004	0.003	0.002	0.006	0.004
SRP					
Michel Ck u/s	0.009	0.002	0.004	0.003	0.004
Michel Ck d/s	0.007	0.002	0.002	0.003	0.004
Bodie Ck	0.007	0.002	0.005	0.008	0.006
Erickson Ck	0.004	0.005	0.008	0.005	0.006
Harmer Ck	0.003	0.003	0.004	0.003	0.003
Six Mile Ck	0.007	0.004	0.004	0.002	0.004
TP					
Michel Ck u/s	0.047	0.007	0.008	0.017	0.020
Michel Ck d/s	0.028	0.006	0.006	0.018	0.014
Bodie Ck	0.31	0.02	0.492	0.012	0.236
Erickson Ck	0.014	0.012	0.019	0.007	0.013
Harmer Ck	0.018	0.010	0.006	0.004	0.010
Six Mile Ck	0.048	0.032	0.036	0.031	0.037

* EP extensive survey data only

the year showed little difference in TDP between effluent and receiving waters. Higher levels of SRP were found in the two receiving water sites in April-June compared to the rest of the year. Concentrations in Erickson and Harmer Creeks at that time compared to the rest of the year, were lower than concentrations in Michel Creek suggesting they were not a source of SRP. Concentrations of SRP at other times were slightly higher in the effluent streams (except, perhaps, Harmer Creek) than the receiving waters. Overall, Bodie and Erickson Creeks contained more SRP than the receiving water sites on Michel Creek. Elevated levels of TP were found in the receiving water sites in April - June and January - March. Mean concentrations in the effluents were variable but, in general, all except Harmer Creek contained higher TP concentrations than the receiving water sites.

A comparison of the loadings in effluent streams and receiving waters suggested that the mine was not a source of TDP but was possibly a SRP and definitely a TP contributor to Michel Creek. The percentage of values above the detection limit were a further indication (Table 25). Contributions of SRP and TP, however, did not affect overall water quality at the downstream Michel Creek sampling site compared to the upstream site.

As with the EP extensive survey results, the four EP intensive surveys found lower levels of TDP downstream of the mine compared to upstream (0.008 mg/L and 0.012 mg/L, respectively) (Table 26). However, elevated levels of TDP were found on the mine property at the Harmer Oxidation Ditch (HOD) discharge (2.6 mg/L), in the upper reaches of Bodie Creek below the HOD (0.036 mg/L), in the seepage into Adit 29S Pit (0.052 mg/L), Bodie Creek at Silver Mile (0.018 mg/L), and possibly in Erickson Creek although the mean was severely affected by one high result. None of the effluent sites with flow data contained significant loadings of TDP relative to the upstream Michel Creek site. While elevated concentrations of TDP were found at the minesite they were not reflected in the major discharges from the mine nor did they affect water quality in Michel Creek at the downstream site.

A comparison of the mean phosphorus species concentrations for the three data sets is shown in Table 27. The change in mean phosphorus concentration in Michel Creek downstream, Bodie Creek, Erickson Creek, Harmer Creek, and Six Mile Creek compared to Michel Creek upstream is also presented. Comparisons of Harmer and Six Mile Creeks to Michel Creek were

TABLE 25 MEAN TDP, SRP, AND TP CONCENTRATIONS GREATER THAN DETECTION LIMIT FOR 1985-86 EP DATA* WESTAR-BALMER

LOCATION	% OF VALUES GREATER THAN DETECTION LIMIT				MEAN FOR YEAR
	APR - JUN	JUL - SEP	OCT - DEC	JAN - MAR	
TDP					
Michel Ck u/s	89	43	64	82	70
Michel Ck d/s	76	29	38	50	48
Bodie Ck	50	43	14	86	48
Erickson Ck	15	100	67	100	70
Harmer Ck	36	33	100	0	42
Six Mile Ck	64	33	0	100	49
SRP					
Michel Ck u/s	87	21	36	27	43
Michel Ck d/s	76	7	15	17	29
Bodie Ck	52	0	100	29	45
Erickson Ck	77	100	100	33	78
Harmer Ck	36	33	100	50	55
Six Mile Ck	64	33	100	0	49
TP					
Michel Ck u/s	100	78	93	64	84
Michel Ck d/s	100	57	85	58	75
Bodie Ck	95	100	100	71	92
Erickson Ck	100	100	100	33	83
Harmer Ck	86	100	100	50	84
Six Mile Ck	100	100	100	100	100

* EP extensive survey data only

TABLE 26 SUMMARY OF WESTAR-BALMER 1985 EP INTENSIVE SURVEY PHOSPHORUS RESULTS

LOCATION	TDP (mg/L) Range (Mean)	SRP (mg/L) Range (Mean)	TP (mg/L) Range (Mean)	LOADING TDP (kg/d) Range (Mean)
Hammer Oxid. Ditch	0.9-4.5(2.6)	0.056-4.4(2.0)	0.156-6.35(3.4)	-
Bodie Ck d/s HOD	0.027-0.045(0.036)	0.021-0.041(0.030)	0.037-1.84(0.64)	0.003(0.003)
Seepage into Adit 29S	0.026-0.117(0.052)	0.014-0.053(0.027)	0.117-3.8(1.6)	-
Pool in Adit 29S	0.008-0.013(0.01)	0.002-0.016(0.007)	0.021-0.61(0.29)	-
Adit 29S Discharge	0.002-0.014(0.008)	0.002-0.076(0.024)	0.108-5(1.4)	0.004-0.009(0.006)
Bodie Creek @ Silver Mile	0.012-0.029(0.018)	0.002-0.018(0.008)	0.012-1.59(1.17)	0.029-0.15(0.079)
Bodie Creek Influent	0.007-0.031(0.014)	0.003-0.017(0.010)	0.006-8.35(3.66)	0.025-0.041(0.033)
Bodie Creek Effluent	0.007-0.021(0.013)	0.002-0.018(0.006)	0.018-0.124(0.080)	0.15-0.11(0.068)
Hammer Ck d/s Waste Rock	0.002-0.005(0.003)	0.002(0.002)	0.002-0.008(0.004)	0.03-0.084(0.053)
Hammer Ck Tributary	0.006-0.009(0.008)	0.003-0.009(0.006)	0.011-0.021(0.016)	-
Hammer Ck Effluent	0.003-0.004(0.003)	0.002-0.009(0.004)	0.005-0.011(0.008)	0.17-0.51(0.32)
Erickson Ck d/s Waste Rock	0.002-0.029(0.013)	0.002-0.003(0.002)	0.002-0.95(0.32)	0.018-0.20(0.085)
Erickson Ck @ Weir	0.002-0.008(0.005)	0.002-0.013(0.006)	0.002-0.013(0.006)	0.022(0.022)
Erickson Ck @ Mouth	0.009-0.013(0.011)	0.011-0.016(0.014)	0.013-0.017(0.015)	0.12-0.39(0.25)
Erickson Tributary	0.009-0.025(0.017)	0.002-0.006(0.004)	0.009-0.025(0.017)	-

TABLE 26 (Continued)

LOCATION	TDP (mg/L) Range (Mean)	SRP (mg/L) Range (Mean)	TP (mg/L) Range (Mean)	LOADING TDP (kg/d) Range (Mean)
Six Mile Cr. Effluent	0.002-0.016(0.010)	0.002-0.018(0.014)	0.002-0.085 (0.042)	0.006-0.074(0.028)
Balmer N. Minewater	0.002-0.009(0.004)	0.002-0.012(0.007)	0.003-0.016(0.010)	0.002-0.01(0.004)
Michel Ck u/s	0.002-0.023(0.012)	0.003-0.026(0.014)	0.006-0.026(0.014)	1.0-90(30)
Michel Ck d/s	0.002-0.019(0.008)	0.002-0.02(0.010)	0.004-0.019(0.010)	1.0-75(22)

TABLE 27 SUMMARY OF MEAN PHOSPHORUS SPECIES CONCENTRATIONS ACCORDING TO VARIOUS DATA SETS - WESTAR-BALMER

LOCATION	1985 ALL DATA		1985-86 EP EXTENSIVE		1985-86 EP INTENSIVE		MEAN CHANGE FROM u/s (mg/L)
	Mean (mg/L)	Change From u/s (mg/L)	Mean (mg/L)	Change From u/s (mg/L)	Mean (mg/L)	Change From u/s (mg/L)	
TDP							
Michel Ck u/s	0.012		0.008		0.012		
Michel Ck d/s	0.011	- 0.001	0.005	- 0.003	0.008	- 0.004	- 0.003
Bodie Ck	0.009	- 0.003	0.008	0	0.013	+ 0.001	- 0.001
Erickson Ck	0.006	- 0.006	0.005	- 0.003	0.011	- 0.001	- 0.003
Harmer Ck	0.003	- 0.009	0.004	- 0.004	0.003	- 0.009	- 0.007
Six Mile Ck	0.005	- 0.007	0.004	- 0.004	0.010	- 0.002	- 0.004
SRP							
Michel Ck u/s	0.007		0.004		0.014		
Michel Ck d/s	0.006	- 0.001	0.004	0	0.010	- 0.004	- 0.002
Bodie Ck	0.018	+ 0.011	0.006	+ 0.002	0.006	- 0.008	+ 0.002
Erickson Ck	0.005	- 0.002	0.006	+ 0.002	0.014	0	0
Harmer Ck	0.003	- 0.004	0.003	- 0.001	0.004	- 0.010	- 0.005
Six Mile Ck	0.006	- 0.001	0.004	0	0.014	0	0
TP							
Michel Ck u/s	0.033		0.020		0.014		
Michel Ck d/s	0.027	- 0.005	0.014	- 0.006	0.009	- 0.005	- 0.005
Bodie Ck	0.268	+ 0.235	0.236	+ 0.216	0.083	+ 0.069	+ 0.173
Erickson Ck	0.015	- 0.018	0.013	- 0.007	0.015	+ 0.001	- 0.008
Harmer Ck	0.015	- 0.018	0.010	- 0.010	0.008	- 0.006	- 0.011
Six Mile Ck	0.043	+ 0.010	0.037	+ 0.017	0.042	+ 0.028	+ 0.018

not strictly valid since the former creeks do not discharge to Michel Creek.

According to the mean change in phosphorus concentration for the three data sets, none of the effluents contributed TDP in concentrations in excess of those recorded at Michel Creek upstream of the mine. For SRP, only Bodie Creek (average 0.002 mg/L above background) may have contributed to the receiving water quality. Both Bodie and Six Mile Creek contributed TP to receiving waters (average 0.173 mg/L and 0.018 mg/L, respectively).

The downstream Michel Creek site contained lower average levels of TDP, SRP, and TP compared to upstream. If effluents were a source of phosphorus to Michel Creek their contributions must have been small and the impacts localized.

4 PREDICTION OF NUTRIENT EXPORT

4.1 Nitrogen Export

The actual total amount of nitrogen released from explosives used in the Kootenay coal fields was about 211 tonnes in 1985 (Fording, Westar-Greenhills, Byron Creek) and 1985-86 (Westar-Balmer, Crows Nest-Line Creek) compared to the 238 tonnes predicted by the Pommen equation (Table 28). Nitrogen release was greater than predicted from the Fording and Westar-Balmer operations and less for Westar-Greenhills, Crows Nest Resources-Line Creek and Byron Creek. The total nitrogen loss amounted to 1.5% of the explosives nitrogen used at the five mines.

TABLE 28 SUMMARY OF INORGANIC NITROGEN EXPORT FROM MINES IN KOOTENAY COAL FIELDS - 1985

MINE	RAW COAL PRODUCTION (tonnes)	EXPLOSIVE USE (tonnes as N)	INORGANIC NITROGEN EXPORT (tonnes as N)	PREDICTED BY POMMEN EQUATION (tonnes as N)
Fording	6,107,000	4,246	102	88
Westar-Balmer*	8,830,000	4,520	101	98
Westar-Greenhills	3,880,000	2,635	3.6	28
Crows Nest-Line Creek*	2,780,000	1,780	2.7	18
Byron Creek	883,000	558	1.4	5.8
TOTAL	22,480,000	13,739	211	238

* data for April 1985 to March 1986

Considering the 15 sets of annual explosives-derived nitrogen loss data from 1980 to 1986 for the five mines examined in this study, the percentage explosives-derived nitrogen loss ranged from 0.1% for the Westar-Greenhills mine in 1985 to 4.3% at the Westar-Balmer operation in 1984. Generally, the five mines could be divided into two groups; three mines exhibited less than 0.3% explosives nitrogen loss (Byron Creek Collieries, Westar-Greenhills, and Crows Nest Resources-Line Creek) and two mines exhibited greater than 1% loss (Fording Coal and Westar-Balmer). The former group of mines used very little slurry explosive (less than 1% as nitrogen) while the latter group used significant amounts (18% to 70%). The high slurry explosive use reflected wet blasting conditions at the Fording Coal and Westar-Balmer mines. The higher percent explosives nitrogen loss associated with mines using slurry explosive confirmed the general relationship found by Pommen.

The percent explosives nitrogen loss versus percent slurry use was plotted to test Pommen's formula that up to 6% of the slurry and 1% of the ANFO could be released from a mine (Figure 30). The relationship with best fit for this data was the following curve:

$$\% \text{ Explosive loss} = 0.34 \times e^{(0.048 \times \% \text{ Slurry})}$$

with a correlation coefficient of 0.76. However, use of this curve would predict very high percent nitrogen loss at high slurry use, a prediction not supported by Fording data. The relationship was skewed by the 1983 and 1984 Westar-Balmer results which were based on company data. As discussed in Section 3.5.2, nitrogen concentration data determined by Westar staff for 1985-86 were significantly higher than those obtained by EP. Analytical difficulties were also reported. The 1983 and 1984 nitrogen loss based on company data may be overestimated. These results are particularly suspect since they were the only annual nitrogen losses significantly underpredicted by the Pommen formula (see Figure 30). If the 1983 and 1984 Westar-Balmer data are ignored, the best fit relationship is a line with the formula:

$$\% \text{ Explosive loss} = (0.045 \times \% \text{ Slurry}) + 0.43$$

The correlation coefficient for the above equation was 0.90 . This equation reasonably predicted the nitrogen loss for our overall data set, but it was not particularly accurate for mines with low slurry use. For those mines, it would be reasonable to assume the mean loss to be 0.2% of the ANFO used (standard deviation of 0.06%). This value, with an appropriate confidence limit, could be used to predict the percent explosives nitrogen loss for mines that do not use significant quantities (ie. less than 1% of total explosive expressed as N) of slurry explosive. The predicted nitrogen release to receiving waters for these mines would be 80% less than that predicted by the Pommen equation.

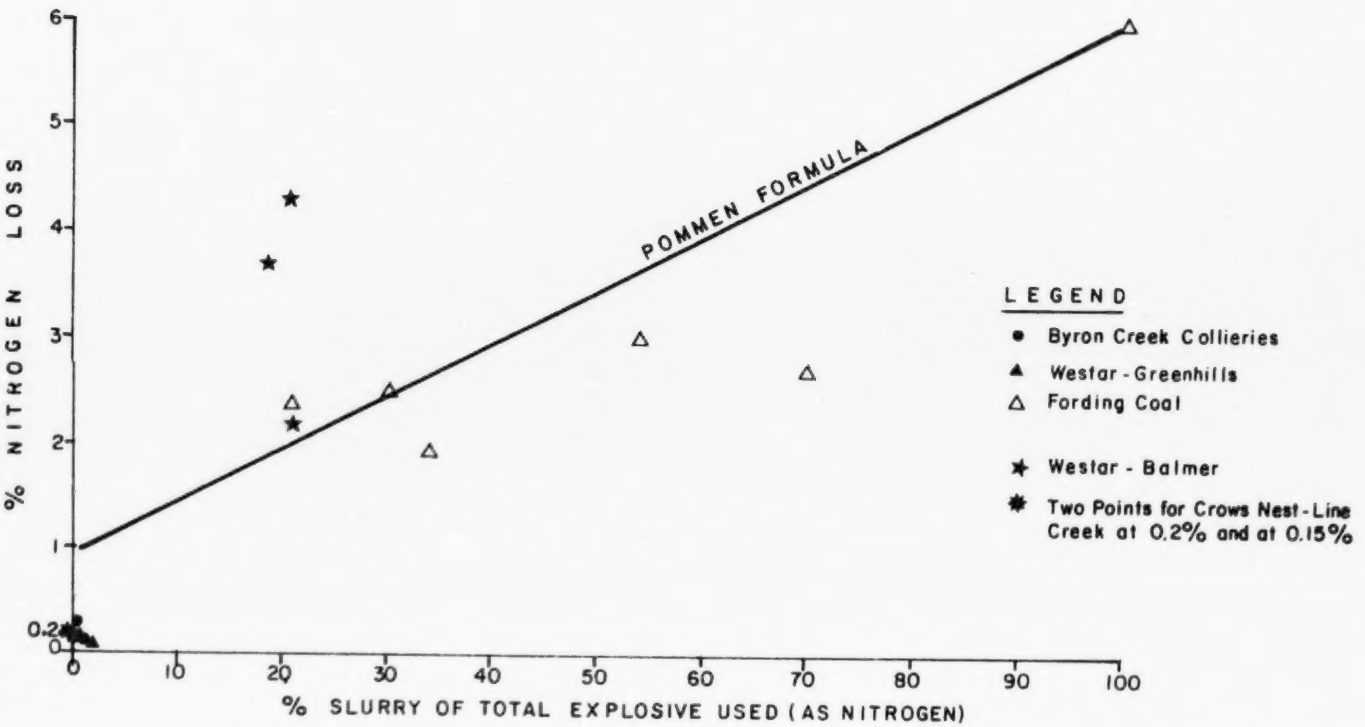

FIGURE 30 PERCENT EXPLOSIVE NITROGEN LOSS WITH SLURRY USE FOR KOOTENAY COAL FIELDS MINES

To develop a predictive model for mines that use significant slurry explosive, the Pommen finding of 6% loss for 100% slurry use at Fording was added to the remaining Westar-Balmer and Fording data (total of 7 results). The best fit was a logarithmic relationship with a correlation coefficient of 0.88, but a linear relationship with a correlation coefficient 0.87 was also close (Figure 31). The linear relationship is recommended for prediction since it is simpler. The best fit linear equation was as follows:

$$\% \text{ Explosive loss} = (0.042 \times \% \text{ Slurry}) + 0.94$$

Written as a proportion of ANFO and slurry use:

$$\text{Explosive loss} = (0.94\% \text{ of ANFO}) + (5.1\% \text{ of Slurry}).$$

This equation is not much different from the Pommen formula but it does reduce the predicted nitrogen release by about 15% at 100% slurry use and 14% at 50% slurry use.

The equation should be used for mines with significant slurry use (ie. greater than 20% total explosive expressed as N). No data are available to assess the nitrogen release for mines which use from 1% to 20% slurry explosive. A conservative assumption would be to use the high slurry use equation for these mines also. However, this would likely result in overly conservative estimates for mines using slightly more than 1% slurry explosive. Alternatively, a linear relationship could be assumed between the 0.2% N loss predicted for mines with less than 1% slurry use and the 1.8% N loss predicted by the high slurry use equation derived above for mines with 20% slurry use. The linear relationship is:

$$\% \text{ Explosive loss} = (0.084 \times \% \text{ Slurry}) + 0.1$$

Written as a proportion of ANFO and slurry use:

$$\text{Explosive loss} = (0.1\% \text{ of ANFO}) + (8.5\% \text{ of Slurry})$$

This latter equation is recommended for mines with greater than 1% and less than 20% slurry explosive use expressed as N.

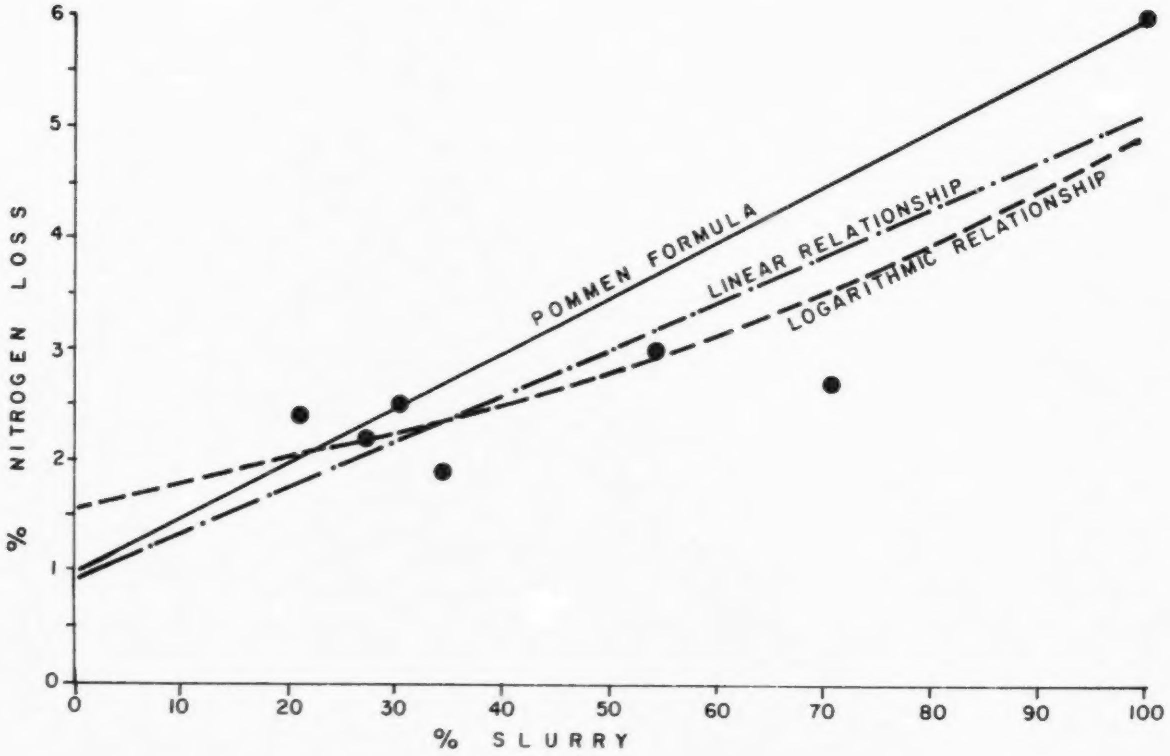

FIGURE 31 EXPLOSIVE NITROGEN LOSS RELATIONSHIP FOR HIGH SLURRY USE MINES

The above equations can be used to predict the amount of nitrogen released from explosives used at coal mines, but loadings should be apportioned according to nitrogen species and season.

Table 29 summarizes the 1985 mean inorganic nitrogen concentrations and loadings for the effluent and receiving water sites examined in this study from all five mines in the Kootenay coal fields. The effluent streams at the Westar-Balmer mine site contained the highest concentrations of ammonia, nitrate, and nitrite. Clode Creek and Swift Creek at the Fording mine contained elevated concentrations of nitrate. A similar pattern was also noted for the mean inorganic nitrogen loading. Effluents at the other two mines contained relatively low concentrations and loadings of inorganic nitrogen. For all effluents, about 87% of the inorganic nitrogen was present as nitrate with only 11% and 2% as ammonia and nitrite, respectively (Table 30). Effluents with higher inorganic nitrogen concentrations (>3 mg/L) contained an even higher percentage of nitrate (95%) while effluents with lower inorganic nitrogen (<0.5 mg/L) contained less (83%).

These percentages could be used to apportion the inorganic nitrogen loading calculated from our predictive formulae to various nitrogen species in effluents. Standard deviations given could be used to develop confidence limits on predicted values with respect to species apportionment.

For receiving waters, the drainages adjacent to the Fording operation contained by far the highest concentration of nitrate nitrogen. Concentrations of ammonia and nitrite were also higher in receiving waters associated with Fording compared to the other mines. Fording also exhibited the greatest increase downstream relative to upstream for mean nitrate concentration (290X) although significant increases were also noted in receiving waters adjacent to the Westar-Balmer (6X) and Byron Creek (4X and 37X for two receiving streams) mines. Loadings of inorganic nitrogen were higher downstream than upstream for all four mines. As such, all these mines were sources of inorganic nitrogen (see individual mine sections for discussion).

For all receiving waters, about 69% of the inorganic nitrogen was present as nitrate with 25% and 11% as ammonia and nitrite, respectively. Upstream sites contained an almost equal proportion of nitrate (47%) and ammonia (43%). Downstream sites, however, contained far more nitrate (87%)

TABLE 29 SUMMARY OF 1985 INORGANIC NITROGEN CONCENTRATIONS AND LOADINGS FOR KOOTENAY COAL FIELD MINES*

EFFLUENTS	MEAN CONCENTRATION (mg/L as N)			MEAN LOADING OF INORGANIC N (kg/d)	% NITROGEN SPECIES OF INORGANIC N (mg/L as N)		
	NH_3/NH_4	NO_3	NO_2		NH_3/NH_4	NO_3	NO_2
Fording Coal Ltd.							
Clode Creek Pond Decant	0.039	3.802	0.017	35.824	1%	98%	1%
Swift Creek	0.025	5.255	0.008	10.874	0.5%	99%	0.5%
Kilmarnock Creek d/s	0.026	0.444	0.004	17.981	5%	94%	1%
Kilmarnock Creek u/s	0.025	0.084	0.003	4.246	22%	75%	3%
Westar Mining Ltd. - Greenhills							
Porter Creek	0.080	0.324	0.003	4.07	20%	80%	0%
Cataract Creek	0.066	0.427	0.007	5.882	13%	85%	2%
Greenhills Creek	0.097	0.373	0.012	5.023	20%	77%	3%
Thompson Creek	0.088	0.274	0.004	3.341	24%	75%	1%
Crows Nest Resources-Line Creek							
Pond #4 Discharge	0.013	0.386	0.004	1.70	3%	96%	1%
No Name Creek	0.008	0.058	0.004	1.746	11%	83%	6%
Westar Mining Ltd. - Balmer							
Harmer Creek	0.063	2.983	0.014	273.153	2%	97%	1%
Bodie Creek	1.531	12.187	0.225	89.295	11%	87%	2%
Erickson Creek at mouth	0.370	7.761	0.013	139.13	4%	95%	1%
Six Mile Creek	0.047	0.240	0.016	1.259	16%	79%	5%
Byron Creek Collieries							
no effluent data analyzed							

* data from all sources

CONTINUED...

TABLE 29 (Continued)

RECEIVING WATERS	MEAN CONCENTRATION (mg/L as N)			MEAN LOADING OF INORGANIC N (kg/d)	% NITROGEN SPECIES OF INORGANIC N (mg/L as N)		
	NH_3/NH_4	NO_3	NO_2		NH_3/NH_4	NO_3	NO_2
Fording Coal Ltd.							
Fording River u/s (FR1)	0.033	0.016	0.003	5.583	63%	31%	6%
Fording River m/s (FR2)	0.068	5.891	0.012	734.27	1%	99%	0%
Fording River d/s (FR4)	0.030	4.689	0.006	438.327	1%	99%	0%
Westar Mining Ltd.-Greenhills							
no receiving waters analyzed							
Crows Nest Resources-Line Creek							
Line Creek u/s	0.013	0.086	0.003	7.165	13%	84%	3%
Line Creek d/s	0.008	0.066	0.005	13.77	10%	84%	6%
Westar Mining Ltd.-Balmer							
Michel Creek u/s	0.027	0.054	0.005	109.295	31%	63%	6%
Michel Creek d/s	0.029	0.342	0.007	304.073	8%	90%	2%
Byron Creek Collieries							
Corbin Creek u/s	< 0.01	0.004	0.003	0.176	42%	33%	25%
Corbin Creek d/s	0.028	0.147	0.004	4.205	16%	82%	2%
Michel Creek u/s	0.027	0.010	0.003	5.325	68%	25%	7%
Michel Creek d/s	0.018	0.045	0.004	6.49	27%	67%	6%

TABLE 30 SUMMARY OF EFFLUENT AND RECEIVING WATER INORGANIC NITROGEN SPECIATION

	NH_3/NH_4			NO_3			NO_2		
	Mean	Range	s*	Mean	Range	s*	Mean	Range	s*
EFFLUENTS									
all	11%	0.5%-24%	8%	87%	75%-99%	9%	2%	0%-6%	2%
high (> 3 mg/l)	4%	0.5%-11%	4%	95%	87%-99%	5%	1%	0.5%-2%	0.5%
low (< 0.5 mg/l)	15%	3%-24%	7%	83%	75%-96%	8%	2%	0%-6%	2%
RECEIVING WATERS									
all	25%	1%-68%	23%	69%	25%-99%	28%	6%	0%-25%	7%
upstream	43%	13%-68%	23%	47%	25%-84%	25%	9%	3%-25%	9%
downstream	10%	1%-27%	10%	87%	67%-99%	12%	3%	0%-6%	3%

* - standard deviation

than ammonia (10%) or nitrite (3%). These findings agreed with the effluent results that the mines were a greater source of nitrate than ammonia or nitrite. These downstream species' percentages could be used to apportion the predicted inorganic load from a mine to receiving waters. That is, the upstream and the mine effluent inorganic N load would be summed and the load at the downstream receiving water site apportioned according to the 87-10-3 relationship for nitrate, ammonia, and nitrite, respectively. This relationship may underestimate the nitrate concentration for high N-releasing mines and overestimate the value for low N-releasing mines as suggested by the inorganic nitrogen speciation data for effluents shown in Table 30. However, standard deviations could be used to develop confidence limits.

Pommen suggested distribution of the predicted nitrogen load over a year with the largest loading occurring during spring snowmelt at interior B.C. mines and during winter rains at coastal mines. Pommen noted that at Fording nitrogen loadings during spring snowmelt were 2 - 4 times the annual average while loadings during low flows were only 0.6 - 0.9 times the annual average.

Data from our study also showed greater proportional loadings during the freshet (April - June, Table 31). For receiving waters, the mean loading for April - June was 1.8 times the mean annual loading compared to 0.5 times for January - March. Effluent ratios were even higher than the receiving water ratios for the April - June freshet (3.1 times mean annual loading). Effluent streams were smaller with more of their catchments at higher elevation compared to receiving waters in the Kootenay coal field. As a result, effluent streams had a higher proportion of flow during freshet periods and were frozen or dry for longer periods than receiving waters. These differences could explain the higher proportion of inorganic nitrogen loading during freshet in effluents compared to receiving waters.

The seasonal ratios suggested by Pommen, or those shown in Table 31 could be used to allocate the annual inorganic nitrogen loading over the year for mines in the Kootenay coal field. However, applicability of these relationships to mines in other climatic regions is not clear. As a first approximation, the annual loading could be allocated according to flow in the effluent or receiving water.

TABLE 31 RATIO OF MEAN QUARTERLY TO MEAN ANNUAL INORGANIC NITROGEN

MINE	LOCATION	JAN-MAR	APR-JUN	JUL-SEP	OCT-DEC
EFFLUENTS					
Westar-Balmer	Bodie Ck*	0.095	1.6	0.82	1.43
	Six Mile Ck*	0.97	2.5	0.12	0.39
Westar-Greenhills	Porter Ck**	0	3.5	0.35	0.28
	Cataract Ck**	0	3.9	0.052	0.085
	Greenhills Ck**	0	3.9	0.029	0
	Thompson Ck**	0	3.2	0.26	0.60
	MEAN	0.2	3.1	0.3	0.4
RECEIVING WATERS					
Westar-Balmer	Michel Ck d/s*	0.61	1.6	0.94	0.80
CNR-Line Creek	Line Ck d/s*	1.0	1.7	0.49	0.84
Byron Creek	Michel Ck d/s**	0.10	2.9	0.38	0.59
	Corbin Ck d/s**	0.40	0.38	2.4	0.79
Fording	Fording R d/s***	0.21	2.2	0.96	0.64
	MEAN	0.5	1.8	1.0	0.7

* 1985-1986 EP extensive survey data
** 1985 company and WMB data
*** 1982 company data

Predicting inorganic nitrogen release prior to mining may be difficult for some operations because the potential use of slurry explosives may be unknown. The need for slurry explosives reflects wet blasting conditions which may depend on a complex interaction of mining, climatic, and hydrogeological factors. These factors are site-specific and beyond the scope of this study. However, in general, mountaintop mining should encounter drier blasting conditions and have lower nitrogen losses relative to valley bottom mining.

In calculating the quantity of nitrogen released from explosives use in a given year, we have assumed that any releases would occur in the same year. Nagpal (1983) indicated nitrogen from explosives would not be expected to remain in the minewaste for more than one year. Releases during the high flow months of May and June should be more rapid compared to the low flow winter months. However, Fording Coal suggest that immediate release of nitrogen from explosives does not necessarily occur in the same year but depends on many factors such as the hydrological cycle, form and intensity of precipitation, drainage exposure, aspect of waste dump, quantity of water, and watershed characteristics (R. Berdusco, personal communication). Releases at Fording Coal are not immediate nor do they occur the same year explosives are used. Nitrogen release is spread over a 5-year or longer time frame. In our study, there was a greater difference in the quantity of nitrogen released between mines than between years for the same mine suggesting broad factors such as total quantity and proportion of explosive type are more important in determining the annual release of nitrogen than minor variations in climate or mining practices. These site-specific factors would more significantly affect releases on a daily or monthly basis. Nitrogen releases from a minesite would not cease when blasting does. However, the total quantity of nitrogen should drop relatively quickly following the first freshet after blasting was completed.

4.2 Phosphorus Export

The analysis of phosphorus data was more difficult compared to nitrogen. Impacts on water quality were not as apparent and concentrations were generally at or near detection limits. In addition, data were examined for only two mines; Crows Nest Resources-Line Creek and Westar-Balmer.

Background levels of phosphorus differed for these two mines with concentrations about twice as high in Michel Creek compared to Line Creek. In general, upstream and downstream water quality in the two creeks did not appear to be significantly different. Nothing can be said about biological impacts since biological indicators were not examined in this study. However, major exports of phosphorus were not apparent in the receiving water quality data, in contrast to the situation for nitrogen. Elevated concentrations of phosphorus were found on the mine property near operations. However, contributions to major effluent streams discharging to receiving waters were variable.

A major objective of this study was to determine if coal mines could be a significant source of phosphorus. Results of the Crows Nest Resources-Line Creek and Westar-Balmer analyses indicated that the mines were not a large source of phosphorus but they may have released small amounts particularly in the total phosphorus form. For other mines, the significance of such a release would vary from mine to mine and would depend on the sensitivity of the receiving waters.

The sensitivity of the receiving waters depends on background concentrations in effluents and receiving waters. Background levels may reflect natural phosphorus in the soils and overburden near the mine. These levels vary throughout the province. For example, levels in the Kootenay coal fields are reported to be higher than those found near the Quinsam Coal mine on Vancouver Island (Hillier et al., 1983).

Of the six major effluents examined from the Crows Nest Resources-Line Creek and Westar-Balmer Mines, five contained average TDP concentrations lower than background. For predictions at other mines, a reasonable assumption may be that TDP levels in major effluents are equal to background receiving water concentrations. A worst case mean concentration, suggested by No Name Creek results at the Line Creek Mine, may be 0.002 mg/L TDP above background.

Four of the six effluents contained average SRP concentrations equal to or lower than upstream receiving water levels. Again, a reasonable prediction for other mines might assume mean annual SRP concentrations equal to background receiving water concentrations. As a worst case, Bodie and No

Name Creek data suggests mean annual concentrations up to 0.002 mg/L above background.

As mentioned previously, both mines appeared to contribute TP to receiving waters. On a mean annual basis, four out of five effluents contained TP at concentrations higher than upstream levels. The average for all six effluents was 0.044 mg/L above upstream receiving water concentrations with a range of -0.011 mg/L to +0.173 mg/L and a standard deviation of 0.0073 mg/L. This mean value, with an appropriate confidence limit, may be a reasonable estimate of the mean annual TP concentration increase to be expected in effluents compared to receiving waters at proposed mines.

Because of the limited phosphorus data base available and the difficulty in drawing firm conclusions, the above guidelines for predictions should be considered as preliminary and used only as a first estimate of phosphorus contributions from mining. Data from natural drainages, groundwater, and discharges from areas disturbed by exploration may provide more realistic estimates of phosphorus releases from mines under consideration. The results of this study suggest the background receiving water phosphorus concentrations are critical data in any estimate of effluent quality.

5 RECOMMENDED PROCEDURE FOR PREDICTING NUTRIENT EXPORT

The following summarizes a recommended procedure for the prediction of annual nutrient release loadings and effluent and receiving water concentrations.

5.1 Nitrogen Export

1. Determine if the proposed mine is likely to encounter wet or dry blasting conditions based on the hydrologic regime (groundwater, surface water, precipitation, evaporation, etc.) and mine plan (dewatering methods).

2. Obtain estimated annual slurry and ANFO use from mine planners for year of interest.

3. Calculate the annual explosive loss as inorganic nitrogen -

   a) for mines which will use up to 1% slurry explosive:

   Explosive loss as N = 0.2% (projected ANFO use as N)

   b) for mines which will use more than 1% but less than 20% slurry explosive expressed as N:

   Explosive loss as N = 0.1% (projected ANFO use as N) +
   8.5% (projected slurry use as N)

   c) for mines which will use more than 20% slurry explosive:

   Explosive loss as N = 0.94% (projected ANFO use as N) +
   5.1% (projected Slurry use as N)

4. Apportion the annual inorganic nitrogen load among effluent and receiving waters based upon the location and percentage size of active waste dumps and pits in each watershed. Active dumps or pits are defined as those which would be in use in the year previous to the date of interest.

5. Apportion the inorganic nitrogen load for effluents into nitrogen species; 87% as nitrate-N, 11% as ammonia-N, and 2% as nitrite-N. For receiving waters, add the upstream and mine effluent inorganic nitrogen load and

assume the downstream load is 87% as nitrate-N, 10% as ammonia-N, and 3% as nitrite-N. (The upstream inorganic nitrogen load would be determined from the baseline receiving water quality monitoring data.)

6. For mines in similar climatic conditions to the Kootenay coal fields, divide the annual load by four and multiply by the following ratios for effluents or receiving waters to determine the load for each quarter of the year.

	JAN.-MAR.	APR.-JUNE	JULY-SEPT.	OCT.-DEC.
Effluents	0.2	3.1	0.3	0.4
Receiving Waters	0.5	1.8	1.0	0.7

To calculate loads for individual days, multiply the ratio of the daily flow to total flow for the quarter by the load for each quarter calculated above.

For mines in different climatic zones than the Kootenay coal fields, loads should probably not be calculated on a daily basis since no data were assessed to evaluate the effect of climate on nitrogen release. Seasonal factors to apportion the load are not available. Loadings on a monthly basis, however, are probably proportional to flow. To calculate monthly loads, apportion according to the ratio of the total monthly flow to total annual flow.

7. Divide daily load by flow to obtain daily concentration (for mines in climatic zones similar to the Kootenay Coal fields).

5.2 Phosphorus Export

1. Determine mean annual upstream receiving water TDP, SRP, and TP concentrations.

2. Assume effluent annual average TDP and SRP concentrations are equal to the upstream concentrations. As a worst case, assume effluent mean annual TDP and SRP concentrations are 0.002 mg/L greater than the mean annual upstream concentration.

3. Calculate effluent mean annual TP concentrations as 0.044 mg/L above upstream receiving water mean annual concentrations.

4. Obtain data from natural drainage from the proposed mining site, groundwater, and exploration discharges for TDP, SRP, and TP. Compare to values calculated above and adjust as required.

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